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(54) Title: COLOR OFFICE PRINTER WITH A HIGH CAPACITY DIGITAL PAGE IMAGE STORE

(57) Abstract

A high speed color printer for use in an office environment, typically as a networked printer. The printer provides high speed (approximately 74 pages per minute: 37 double sided sheets per minute), high printing resolution (800 dpi) full color printer which incorporates electronic collation and local storage of 1,000 or more rasterized pages. The invention utilizes advances in high resolution pagewidth drop on demand print heads. Also incorporated is a new image compression and real-time expansion system for electronic collation and local document storage. The image resolution and compression quality is specified to achieve an image quality comparable with current magazine and brochure printing using color offset presses. A high speed color commercial printing system uses continuous roll media with a print speed of approximately 148 A4 pages per minute, electronic collation and local storage of 10,000 or more pages.
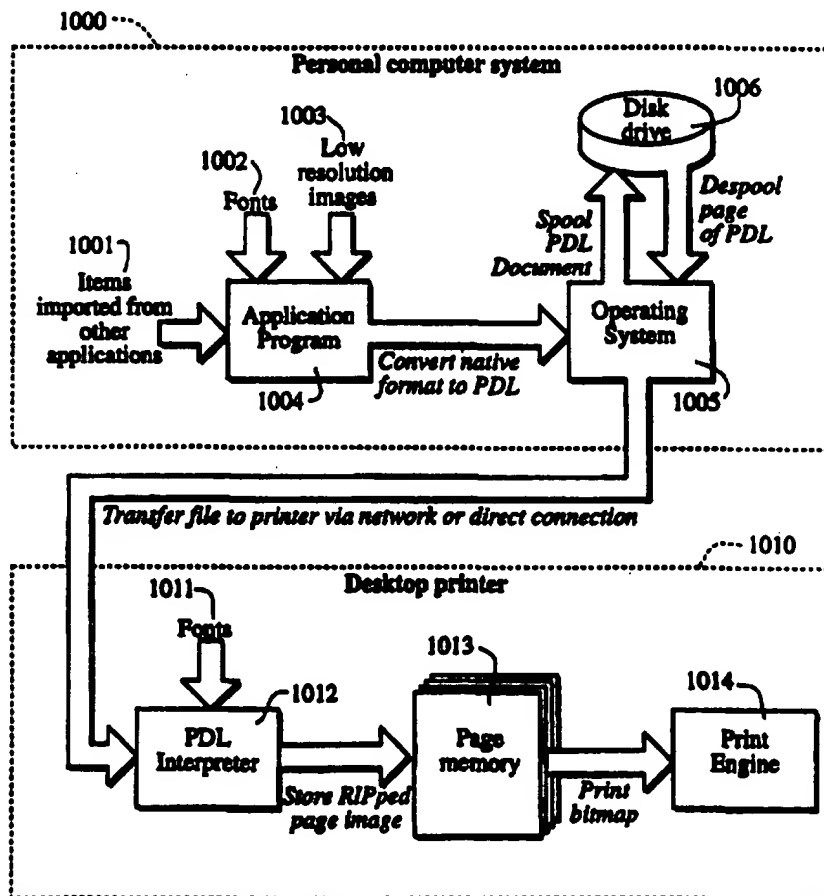
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COLOR OFFICE PRINTERW1TH A HIGH CAPACITY
DIGITAL PAGE IMAGE STORE
Field of the Invention
The present invention is in the field of computer controlled printing devices. In particular, the field is color
office printers using drop on demand printing systems.

Background of the Invention
Many different types of digitally controlled printing systems have been invented, and many types are
currently in production. These printing systems use a variety of actuation mechanisms, a variety of marking
materials, and a variety of recording media. Examples of digital printing systems in current use include: laser
electrophotographic printers; LED electrophotographic printers; dot matrix impact printers; thermal paper
printers; film recorders; thermal wax printers; dye diffusion thermal transfer printers; and ink jet printers.
However, at present, such electronic printing systems have not significantly replaced mechanical printing
presses, even though this conventional method requires very expensive setup and is seldom commercially
viable unless a few thousand copies of a particular page are to be printed.Thus, there is a need for improved
digitally controlled printing systems, for example, being able to produce high quality color images at a high-
speed and low cost, using standard paper.

Inkjet printing has become recognized as a prominent contender in the digitally controlled, electronic printing
arena because, e.g., of its non-impact, low-noise characteristics, its use of plain paper and its avoidance of
toner transfers and fixing.

Many types of ink jet printing mechanisms have been invented.

These can be categorized as either continuous ink jet(CIJ) or drop on demand (DOD) ink jet. Continuous ink
jet printing dates back to at least 1929: Hansell, US
Pat. No. 1,941,001.

Sweet et al US Pat. No. 3,373,437, 1967, discloses an array of continuous ink jet nozzles where ink drops to
be printed are selectively charged and deflected towards the recording medium. This technique is known as
binary deflection CU, and is used by several manufacturers, including Elmjet and Scitex.

Hertz et al US Pat. No. 3,416,153, 1966, discloses a method of achieving variable optical density of printed
spots in CU printing using the electrostatic dispersion of a charged drop stream to modulate the number of
droplets which pass through a small aperture. This technique is used in ink jet printers manufactured by Iris
Graphics.

Kyser et al US Pat. No. 3,946,398, 1970, discloses a DOD ink jet printer which applies a high voltage to a
piezoelectric crystal, causing the crystal to bend, applying pressure on an ink reservoir and jetting drops on
demand. Many types of piezoelectric drop on demand printers have subsequently been invented, which
utilize piezoelectric crystals in bend mode, push mode, shear mode, and squeeze mode. Piezoelectric DOD
printers have achieved commercial success using hot melt inks (for example, Tektronix and Dataproducts
printers), and at image resolutions up to 720 dpi for home and office printers (Seiko Epson). Piezoelectric
DOD printers have an advantage in being able to use a wide range of inks.

However, piezoelectric printing mechanisms usually require complex high voltage drive circuitry and buLky
piezoelectric crystal arrays, which are disadvantageous in regard to manufacturability and performance.

Endo et alGB Pat. No. 2,007,162, 1979, discloses an electrothermal
DOD ink jet printer which applies a power pulse to an electrothermal transducer (heater) which is in thermal
contact with ink in a nozzle. The heater rapidly heats water based ink to a high temperature, whereupon a
small quantity of ink rapidly evaporates, forming a bubble. The formation of these bubbles results in a
pressure wave which cause drops of ink to be ejected from small apertures along the edge of the heater
substrate. This technology is known asBubblejetIM (trademark of Canon
KK. of Japan), and is used in a wide range of printing systems from Canon, Xerox, and other manufacturers.

Vaught et al US Pat. No. 4,490,728, 1982, discloses an electrothermal drop ejection system which also
operates by bubble formation. In this system, drops are ejected in a direction normal to the plane of the

heater substrate, through nozzles formed in an aperture plate positioned above the heater.

This system is known as Thermal Ink Jet, and is manufactured by Hewlett-Packard.

In this document, the term Thermal Ink Jet is used to refer to both the Hewlett
Packard system and systems commonly known asBubblejetTM.

Thermal Ink Jet printing typically requires approximately 20WJ over a period of approximately 2Zs to eject
each drop. The 10 Watt active power consumption of each heater is disadvantageous in itself and also
necessitates special inks, complicates the driver electronics and precipitates deterioration of heater
elements.

Other ink jet printing systems have also been described in technical literature, but are not currently used on a
commercial basis. For example, U.S.

Patent No. 4,275,290 discloses a system wherein the coincident address of predetermined print head
nozzles with heat pulses and hydrostatic pressure, allows ink to flow freely to spacer-separated paper,
passing beneath the print head. U.S.

Patent Nos. 4,737,803; 4,737,803 and 4,748,458 disclose ink jet recording systems wherein the coincident
address of ink in print head nozzles with heat pulses and an electrostatically attractive field cause ejection of
ink drops to a print sheet
Each of the above-described inkjet printing systems has advantages and disadvantages. However, there
remains a widely recognized need for an improved ink jet printing approach, providing advantages for
example, as to cost, speed, quality, reliability, power usage, simplicity of construction and operation,
durability and consumables.

Summary of theinvention
My concurrently filed applications, entitled "Liquid Ink Printing Apparatus and System" and "Coincident Drop-
Selection, Drop-Separation Printing Method and System" describe new methods and apparatus that afford
significant improvements toward overcoming the prior art problems discussed above. Those inventions offer
important advantages, e.g., in regard to drop size and placement accuracy, as to printing speeds attainable,
as to power usage, as to durability and operative thermal stresses encountered and as to other printer
performance characteristics, as well as in regard to manufacturability and the characteristics of useful inks.
One important purpose of the present invention is to further enhance the structures and methods described
in those applications and thereby contribute to the advancement of printing technology.

One object of the present invention is to provide liquid ink printing systems which afford significant
advantages toward attaining the above-noted advantages. The invention provides a printing apparatus using
cut sheet or continuous roll recording media which incorporates a high capacity compressed document
image storage apparatus including: 1) an image creation system which can operate on a band-by-band
basis; 2) an input memory which stores at least one band of the uncompressed page image, but less than
50% of the uncompressed page image; 3) a page image compression system which can operate on a band-
by-band basis; 4) a mass storage device able to store a plurality of compressed page images; 5) a page
image expansion system which expands compressed page image data to form an expanded page image at
a rate which is within 20% of the page printing rate when measured over the duration of the page printing
time; 6) an output memory which stores at least one band of the expanded page image, but less than 50% of
the expanded page image; and 7) an apparatus which provides page image data from the output memory to
a printing device wherein the time taken to provide a band of image data to the printing device does not vary
by more than+50% of the mean time to provide a band of image data to the printing device.

A preferred form of the invention is that the printing mechanism of the printing apparatus operates on a drop
selection and separation printing principle.

A further preferred form of the invention is that the color model used in the printing apparatus is CC'MM'YK.

The invention also provides a printing apparatus using cut sheet recording media which incorporates
electronic collation wherein the printing mechanism of the printing apparatus operates on the drop selection
and separation printing principle.

The invention also provides a printing apparatus using cut sheet recording media which incorporates

compressed digital document storage wherein the printing mechanism of the printing apparatus operates on the drop selection and separation printing principle.

Bnef DescnDtlon of theDraumgs
Figure1 (a) shows a simplified block schematic diagram of one exemplary printing apparatus according to the present invention.

Figure1 (b) shows a cross section of one variety of nozzle tip in accordance with the invention.

Figures 2(a) to 2(f) show fluid dynamic simulations of drop selection.

Figure 3(a) shows a finite element fluid dynamic simulation of a nozzle in operation according to an embodiment of the invention.

Figure 3(b) shows successive meniscus positions during drop selection and separation.

Figure 3(c) shows the temperatures at various points during a
Thermal LIFT drop selection cycle.

Figure 3(d) shows measured surface tension versus temperature curves for various ink additives.

Figure 3(e) shows the power pulses which are applied to the nozzle heater to generate the temperature curves of figure 3(c)
Figure 4 shows a block schematic diagram of print head drive circuitry for practice of the invention.

Figure 5 shows projected manufacturing yields for an A4 page width color print head embodying features of the invention, with and without fault tolerance.

Figure 6 is a block schematic diagram of a typical current office or home printing system.

Figure 7 is a block schematic diagram of a typical current commercial printing system.

Figures 8(a) and 8(b) are block schematic diagrams of typical commercial and office printing systems, respectively, using page image compression for electronic collation and print on demand digital page storage.

Figure 9 is a diagram representing the data encoding scheme of the page image compression system.

Figures 10(a) and 10(b) are an example set of patterns to which subcells may be matched for encoding.

Figures11 (a) and11 (b) are block schematic diagrams of a real-time page image expansion system for high speed color printing.

Figure 12 is a perspective diagram of a high speed color office printer which incorporates a drop selection and separation printing mechanism, electronic collation and local page storage.

Figure 13 is a perspective diagram of a high speed commercial color printer which incorporates a drop selection and separation printing mechanism, electronic collation and local page storage.

Figure 14 is a detail perspective diagram of the print head region of the printer shown in figure 13.

Figure 15 is a perspective diagram of a paper roll and frame for use in the printer shown in Figure 13.

DetailedDescnption of PreferredEmbodlments
One aspect of the current invention constitutes a high speed color printer for use in an office environment, typically as a networked printer. Currently available high speed office printers are typically based on laser electrophotographic technology. The maximum print speed commonly available in color office printers is approximately 4 pages per minute for color laser printers, and 2 minutes per page for color ink jet printers. Currently, office printers typically do not provide electronic collation or local storage of pre-rasterized documents. This means that documents must be rasterized every time they are printed, and that manual collation is often required.

The current invention provides a high speed (approximately 74 pages per minute: 37 double sided sheets per minute), high printing resolution (800 dpi) full color printer which incorporates electronic collation and local storage of 1,000 or more rastereeed pages. The invention utilizes advances in high resolution pagewidth drop on demand print heads. Also incorporated is a new image compression and real-time expansion system for electronic collation and local document storage. The image resolution and compression quality is specified to achieve an image quality comparable with current magazine and brochure printing using color offset presses.

Another aspect of the current invention constitutes a high speed color commercial printing system using continuous roll print media At present, most high volume full color printing is performed by web fed and sheet fed offset color presses. These machines print color pages using four etched printing plates, one for each of the four color components used in process printing; cyan, magenta, yellow, and black (CMYK). While these machines are highly efficient in printing large volumes of color pages, it is difficult, time consuming, and expensive to change the image being printed. If the print run is greater than 10,000 copies, the set-up costs of the press can be effectively amortized over the volume printed.

However, the cost and time required to set up a color press mean that only rarely is fewer than 1,000 copies of a page printed. If fewer than one hundred copies of a page are to be printed, then color copiers are generally used.

There is increasing recognition in the industry of the need for digital color printing presses, which are capable of printing high quality color pages directly from computer data, without requiring photographic and platemaking processes. These are considered to be most cost effective for print runs of between 100 copies and 10,000 copies. Two short run direct digital color presses were commercially released in 1993. These are the DCP-1 from Xeikon of Belgium, and the E-Print 1000 from Indigo of Israel. The Xeikon DCP-1 is a dry Xerographic system with a print speed of 33 A4 pages per minute for four color process work.

The system is web-fed. The Indigo E-Print 1000 is a sheetfed digital offset press that can print up to six colors on a standard sheet size of A3. It runs at a rate up to 67 single color A3 impressions per minute. It operates using some of the same principles as traditional offset printing, using plates, blankets, and impression cylinders with liquid ink. A laser beam is scanned across a photoconductor image cylinder, which attracts liquid ink, which is then transferred to the blanket cylinder and then is 'offset' to the paper held on the impression cylinder. The image resolution is 800 dpi. The E-Print 1000 includes an optional collating and binding system, and has internal duplexing for printing on both sides of the paper.

While these two machines are viable for short run printing, they are not suitable as replacements for offset presses for medium or large run printing. The throughput is substantially lower, and cost per page substantially higher, than offset printing for print runs in excess of a few thousand copies. Although these machines can be used in parallel to increase the overall printing throughput, the cost of these systems is quite high (in excess of $US 200,000 for color systems). The capital cost combined with the high cost per page makes parallel systems not cost competitive with traditional offset printing for medium or large print runs.

Problems also exist in using currently available machines for short run color, especially where the print run is less than 10 copies. In this case, the total print time is usually dominated by the time required to rasterizePostscriptTM pages, and the full print speed of the print engines cannot be utilized.

According to this aspect of the current invention, a high speed (approximately 148 A4 pages per minute), high printing resolution (800 dpi) full color printer which incorporates electronic collation and local storage of 10,000 or more rasterized pages. The invention utilizes advances in high resolution pagewidth drop on demand print heads. Also incorporated is a new image compression and real-time expansion system for electronic collation and local document storage, which can print stored pages in any sequence at the full printing speed of the print engine. The image resolution and compression quality is specified to achieve an image quality comparable with current magazine and brochure printing using color offset presses.

Capital cost is normally not a critical factor in commercial printing equipment. Cost per page and throughput are, however, important considerations.

The system disclosed herein has potential for low cost per page, as the only consumables are ink, paper, and a small amount of electricity. Throughput of a single machine is high, though still considerably lower than

high speed color offset presses. The digital printing systems disclosed herein can readily be operated in parallel, as the capital cost and floor space are a small fraction of color offset press requirements. Thus systems with throughput equivalent to, or exceeding, that of color offset presses can readily be assembled.

In one general aspect, the invention constitutes a drop-on-demand printing mechanism wherein the means of selecting drops to be printed produces a difference in position between selected drops and drops which are not selected, but which is insufficient to cause the ink drops to overcome the ink surface tension and separate from the body of ink, and wherein an alternative means is provided to cause separation of the selected drops from the body of ink.

The separation of drop selection means from drop separation means significantly reduces the energy required to select which ink drops are to be printed. Only the drop selection means must be driven by individual signals to each nozzle. The drop separation means can be a field or condition applied simultaneously to all nozzles.

The drop selection means may be chosen from, but is not limited to, the following list: 1) Electrothermal reduction of surface tension of pressurized ink 2) Electrothermal bubble generation, with insufficient bubble volume to cause drop ejection 3) Piezoelectric, with insufficient volume change to cause drop ejection 4) Electrostatic attraction with one electrode per nozzle
The drop separation means may be chosen from, but is not limited to, the following list: 1) Proximity (recording medium in close proximity to print head) 2) Proximity with oscillating ink pressure 3) Electrostatic attraction 4) Magnetic attraction
The table "DOD printing technology targets" shows some desirable characteristics of drop on demand printing technology.The table also lists some methods by which some embodiments described herein, or in other of my related applications, provide improvements over the prior art.

DOD printing technology targets
EMI10.1

<tb>Tar <SEP> Ct <SEP> <SEP> Method <SEP> of <SEP> achievin <SEP> im <SEP> rovement <SEP> over <SEP> rior <SEP> art <SEP>
<tb> High <SEP> speed <SEP> operation <SEP> Practical, <SEP> low <SEP> cost, <SEP> pagewidth <SEP> printing <SEP> heads <SEP> with <SEP> more
<tb> <SEP> than <SEP> 10,000 <SEP> nozzles.<SEP> Monolithic <SEP> A4 <SEP> pagewidth <SEP> print
<tb> <SEP> heads <SEP> can <SEP> be <SEP> manufactured <SEP> using <SEP> standard <SEP> 300 <SEP> mm
<tb> <SEP> (12") <SEP> silicon <SEP> wafers
<tb> High <SEP> image <SEP> quality <SEP> High <SEP> resolution <SEP> (800 <SEP> dpi <SEP> is <SEP> sufficient <SEP> for <SEP> most
<tb> <SEP> applications), <SEP> six <SEP> color <SEP> process <SEP> to <SEP> reduce <SEP> image <SEP> noise
<tb> Full <SEP> color <SEP> operation <SEP> Halftoned <SEP> process <SEP> color <SEP> at <SEP> 800 <SEP> dpi <SEP> using <SEP> stochastic
<tb> <SEP> screening
<tb> Ink <SEP> flexibility <SEP> Low <SEP> operating <SEP> ink <SEP> temperature <SEP> and <SEP> no <SEP> requirement <SEP> for
<tb> <SEP> bubble <SEP> formation
<tb> Low <SEP> power <SEP> Low <SEP> power <SEP> operation <SEP> results <SEP> from <SEP> drop <SEP> selection <SEP> means
<tb> requirements <SEP> not <SEP> being <SEP> required <SEP> to <SEP> fully <SEP> eject <SEP> drop
<tb> Low <SEP> cost <SEP> Monolithic <SEP> print <SEP> head <SEP> without <SEP> aperture <SEP> plate, <SEP> high
<tb> <SEP> manufacturing <SEP> yield, <SEP> small <SEP> number <SEP> of <SEP> electrical
<tb> <SEP> connections, <SEP> use <SEP> of <SEP> modified <SEP> existing <SEP> CMOS
<tb> <SEP> manufacturing <SEP> facilities
<tb> High <SEP> manufacturing <SEP> Integrated <SEP> fault <SEP> tolerance <SEP> in <SEP> printing <SEP> head
<tb> yield

<tb> High <SEP> reliability <SEP> Integrated <SEP> fault <SEP> tolerance <SEP> in <SEP> printing
<SEP> head. <SEP> Elimination
<tb> <SEP> of <SEP> cavitation <SEP> and <SEP> kogation. <SEP> Reduction <SEP> of <SEP> thermal
<SEP> shock.
<tb>

Small <SEP> number <SEP> of <SEP> Shift <SEP> registers, <SEP> control <SEP> logic, <SEP> and
<SEP> drive <SEP> circuitry <SEP> can <SEP> be
<tb> electrical <SEP> connections <SEP> integrated <SEP> on <SEP> a <SEP> monolithic <SEP> print
<SEP> head <SEP> using <SEP> standard
<tb> <SEP> CMOS <SEP> processes
<tb> Use <SEP> of <SEP> existing <SEP> VLSI <SEP> CMOS <SEP> compatibility.<SEP> This <SEP>
can <SEP> be <SEP> achieved <SEP> because <SEP> the
<tb> manufacturing <SEP> heater <SEP> drive <SEP> power <SEP> is <SEP> less <SEP> is <SEP> than
<SEP> 1% <SEP> of <SEP> Thermal <SEP> Ink <SEP> Jet
<tb> facilities <SEP> heater <SEP> drive <SEP> power
<tb>
EMI11.1

<tb> Electronic <SEP> collation <SEP> A <SEP> new <SEP> page <SEP> compression <SEP> system
<SEP> which <SEP> can <SEP> achieve
<tb> <SEP> 100:1 <SEP> compression <SEP> with <SEP> insignificant <SEP> image
<tb> <SEP> degradation, <SEP> resulting <SEP> in <SEP> a <SEP> compressed <SEP> data <SEP> rate
<SEP> low
<tb> <SEP> enough <SEP> to <SEP> allow <SEP> real-time <SEP> printing <SEP> of <SEP> any <SEP>
combination
<tb> <SEP> of <SEP> thousands <SEP> of <SEP> pages <SEP> stored <SEP> on <SEP> a <SEP> low
<SEP> cost <SEP> magnetic
<tb> <SEP> disk <SEP> drive.
<tb>

In thermal ink jet (CHIV) and piezoelectric ink jet systems, a drop velocity of approximately 10 meters per second is preferred to ensure that the selected ink drops overcome ink surface tension, separate from the body of the ink, and strike the recording medium. These systems have a very low efficiency of conversion of electrical energy into drop kinetic energy. The efficiency of TIJ systems is approximately 0.02%). This means that the drive circuits for TU print heads must switch high currents. The drive circuits for piezoelectric ink jet heads must either switch high voltages, or drive highly capacitive loads. The total power consumption of pagewidth TIJ printheads is also very high.An 800 dpi A4 full color pagewidth TIJ print head printing a four color black image in one second would consume approximately 6 kW of electrical power, most of which is converted to waste heat. The difficulties of removal of this amount of heat precludes the production of low cost, high speed, high resolution compact pagewidthTU systems.

One important feature of embodiments of the invention is a means of significantly reducing the energy required to select which ink drops are to be printed. This is achieved by separating the means for selecting ink drops from the means for ensuring that selected drops separate from the body of ink and form dots on the recording medium. Only the drop selection means must be driven by individual signals to each nozzle. The drop separation means can be a field or condition applied simultaneously to all nozzles.

The table"Drop selection means" shows some of the possible means for selecting drops in accordance with the invention. The drop selection means is only required to create sufficient change in the position of selected drops that the drop separation means can discriminate between selected and unselected drops.
Drop selection means
EMI12.1

<tb> Method <SEP> Advantage <SEP> Limitation
<tb> 1. <SEP> Electrothermzrl <SEP> Low <SEP> temperature <SEP> Requires <SEP> ink <SEP>
pressure
<tb> reduction <SEP> ofsurface <SEP> increase <SEP> and <SEP> low <SEP> drop <SEP> regulating
<SEP> mechanism. <SEP> Ink

<tb> tension <SEP> of <SEP> selection <SEP> energy. <SEP> Can <SEP> be <SEP> surface <SEP> tension <SEP> must <SEP> reduce
<tb> pressurized <SEP> ink <SEP> used <SEP> with <SEP> many <SEP> ink <SEP> substantially <SEP> as <SEP> temperature
<tb> <SEP> types.<SEP> Simple <SEP> fabrication. <SEP> increases
<tb> <SEP> CMOS <SEP> drive <SEP> circuits <SEP> can
<tb> <SEP> be <SEP> fabricated <SEP> on <SEP> same
<tb> <SEP> substrate
<tb> 2. <SEP> Electrothermal <SEP> Medium <SEP> drop <SEP> selection <SEP> Requires <SEP> ink <SEP> pressure
<tb> reduction <SEP> of <SEP> ink <SEP> energy, <SEP> suitable <SEP> for <SEP> hot <SEP> oscillation <SEP> mechanism. <SEP> Ink
<tb> viscosity, <SEP> combined <SEP> melt <SEP> and <SEP> oil <SEP> based <SEP> inks. <SEP> must <SEP> have <SEP> a <SEP> large <SEP> decrease
<tb> with <SEP> oscillating <SEP> ink <SEP> Simple <SEP> fabrication. <SEP> in <SEP> viscosity <SEP> as <SEP> temperature
<tb> pressure <SEP> CMOS <SEP> drive <SEP> circuits <SEP> can <SEP> increases
<tb> <SEP> be <SEP> fabricated <SEP> on <SEP> same
<tb> <SEP> substrate
<tb> 3.<SEP> Electrothermal <SEP> Well <SEP> known <SEP> technology, <SEP> High <SEP> drop <SEP> selection <SEP> energy,
<tb> bubble <SEP> generation, <SEP> simple <SEP> fabrication, <SEP> requires <SEP> water <SEP> based <SEP> ink,
<tb> with <SEP> insufficent <SEP> bipolar <SEP> drive <SEP> circuits <SEP> can <SEP> problems <SEP> with <SEP> kogation,
<tb> bubble <SEP> volpme <SEP> to <SEP> be <SEP> fabricated <SEP> on <SEP> same <SEP> cavitation, <SEP> thermal <SEP> sess
<tb> cause <SEP> drop <SEP> ejection <SEP> substrate
<tb> 4.<SEP> Piezoelectric, <SEP> with <SEP> Many <SEP> types <SEP> of <SEP> ink <SEP> base <SEP> High <SEP> manufacturing <SEP> cost,
<tb> insufficient <SEP> volume <SEP> can <SEP> be <SEP> used <SEP> incompatible <SEP> with
<tb> change <SEP> to <SEP> cause <SEP> drop <SEP> integrated <SEP> circuit <SEP> processes,
<tb> ejection <SEP> high <SEP> drive <SEP> voltage,
<tb> <SEP> mechanical <SEP> complexity,
<tb> <SEP> buLb
<tb>5. <SEP> Electrostatic <SEP> Simple <SEP> electrode <SEP> Nozzle <SEP> pitch <SEP> must <SEP> be
<tb> attraction <SEP> with <SEP> one <SEP> fabrication <SEP> relatively <SEP> large. <SEP> Crosstalk
<tb> electrode <SEP> per <SEP> nozzle <SEP> between <SEP> adjacent <SEP> electric
<tb> <SEP> fields. <SEP> Requires <SEP> high
<tb> <SEP> voltage <SEP> drive <SEP> circuits
<tb>
Other drop selection means may also be used.

The preferred drop selection means for water based inks is method 1: "Electrothermal reduction of surface tension of pressurized ink". This drop selection means provides many advantages over other systems, including; low power operation (approximately 1% ofTV), compatibility with CMOS VLSI chip fabrication, low voltage operation (approx. 10 V), high nozzle density, low temperature operation, and wide range of suitable ink formulations. The ink must exhibit a reduction in surface tension with increasing temperature.

The preferred drop selection means for hot melt or oil based inks is method 2: "Electrothermal reduction of ink viscosity, combined with oscillating ink pressure". This drop selection means is particularly suited for use with inks which exhibit a large reduction of viscosity with increasing temperature, but only a small reduction in surface tension. This occurs particularly with non-polar ink carriers with relatively high molecular weight. This is especially applicable to hot melt and oil based inks.

The table "Drop separation means" shows some of the possible methods for separating selected drops from the body of ink, and ensuring that the selected drops form dots on the printing medium. The drop separation means discriminates between selected drops and unselected drops to ensure that unselected drops do not form dots on the printing medium.

Drop separation means
EMI13.1

<tb> Means <SEP> Advantage <SEP> Limitation
<tb> 1. <SEP> Electrostatic <SEP> Can <SEP> print <SEP> on <SEP> rough <SEP> Requires <SEP> high <SEP> voltage
<tb> attraction <SEP> surfaces, <SEP> simple <SEP> power <SEP> supply
<tb> <SEP> implementation
<tb> 2. <SEP> AC <SEP> electric <SEP> field <SEP> Higher <SEP> field <SEP> strength <SEP> is <SEP> Requires <SEP> high <SEP> voltage <SEP> AC
<tb> <SEP> possible <SEP> than <SEP> electrostatic, <SEP> power <SEP> supply <SEP> synchronized
<tb> <SEP> operating <SEP> margins <SEP> can <SEP> be <SEP> to <SEP> drop <SEP> ejection <SEP> phase.
<tb>

<SEP> increased, <SEP> ink <SEP> pressure <SEP> Multiple <SEP> drop <SEP> phase
<tb> <SEP> reduced, <SEP> and <SEP> dust <SEP> operation <SEP> is <SEP> difficult
<tb> <SEP> accumulation <SEP> is <SEP> reduced
<tb> 3. <SEP> Proximity <SEP> Very <SEP> small <SEP> spot <SEP> sizes <SEP> can <SEP> Requires <SEP> print <SEP> medium <SEP> to <SEP> be
<tb> (print <SEP> head <SEP> in <SEP> close <SEP> be <SEP> achieved. <SEP> Very <SEP> low <SEP> very <SEP> close <SEP> to <SEP> print <SEP> head
<tb> proximity <SEP> to, <SEP> but <SEP> power <SEP> dissipation. <SEP> High <SEP> surface, <SEP> not <SEP> suitable <SEP> for
<tb> not <SEP> touching, <SEP> drop <SEP> position <SEP> accuracy <SEP> rough <SEP> print <SEP> media, <SEP> usually
<tb> recording <SEP> medium) <SEP> requires <SEP> transfer <SEP> roller <SEP> or
<tb> <SEP> belt
<tb>
EMI14.1

<tb> 4.<SEP> Transfer <SEP> Very <SEP> small <SEP> spot <SEP> sizes <SEP> can <SEP> Not <SEP> compact <SEP> due <SEP> to <SEP> size <SEP> of
<tb> Proximity <SEP> (print <SEP> be <SEP> achieved, <SEP> very <SEP> low <SEP> transfer <SEP> roller <SEP> or <SEP> transfer
<tb> head <SEP> is <SEP> in <SEP> close <SEP> power <SEP> dissipation, <SEP> high <SEP> belt.
<tb> proximity <SEP> to <SEP> a <SEP> accuracy, <SEP> can <SEP> print <SEP> on
<tb> transfer <SEP> roller <SEP> or <SEP> rough <SEP> paper
<tb> belt
<tb> 5.<SEP> Proximity <SEP> with <SEP> Useful <SEP> for <SEP> hot <SEP> melt <SEP> inks <SEP> Requires <SEP> print <SEP> medium <SEP> to <SEP> be
<tb> oscillating <SEP> ink <SEP> using <SEP> viscosity <SEP> reduction <SEP> very <SEP> close <SEP> to <SEP> print <SEP> head
<tb> pressure <SEP> drop <SEP> selection <SEP> method, <SEP> surface, <SEP> not <SEP> suitable <SEP> for
<tb> <SEP> reduces <SEP> possibility <SEP> of <SEP> rough <SEP> print <SEP> media. <SEP> Requires
<tb> <SEP> nozzle <SEP> clogging, <SEP> can <SEP> use <SEP> ink <SEP> pressure <SEP> oscillation
<tb> <SEP> pigments <SEP> instead <SEP> of <SEP> dyes <SEP> apparatus
<tb> 6. <SEP> Magnetic <SEP> Can <SEP> print <SEP> on <SEP> rough <SEP> Requires <SEP> uniform <SEP> high
<tb> attraction <SEP> surfaces.<SEP> Low <SEP> power <SEP> if <SEP> magnetic <SEP> field <SEP> strength,
<tb> <SEP> permanent <SEP> magnets <SEP> are <SEP> requires <SEP> magnetic <SEP> ink
<tb> <SEP> used
<tb>

Other drop separation means may also be used.

The preferred drop separation means depends upon the intended use.

For most applications, method 1: "Electrostatic attraction", or method 2: "AC electric field" are most appropriate. For applications where smooth coated paper or film is used, and very high speed is not essential, method 3: "Proximity" may be appropriate. For high speed, high quality systems, method 4: "Transfer proximity" can be used. Method 6: "Magnetic attraction" is appropriate for portable printing systems where the print medium is too rough for proximity printing, and the high voltages required for electrostatic drop separation are undesirable. There is no clear 'best' drop separation means which is applicable to all circumstances.

Further details of various types of printing systems according to the present invention are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:
'A Liquid ink Fault Tolerant(LIFT) printing mechanism' (Filing no.:
PN2308);
'Electrothermal drop selection in LIFT printing' (Filing no.: PN2309);
'Drop separation inLIFI printing by print media proximity' (Filing no.:
PN2310);
'Drop size adjustment in Proximity LIFT printing by varying head to media distance' (Filing no.: PN2311);
'Augmenting Proximity LIFT printing with acoustic ink waves' (Filing no.: PN2312);
'Electrostatic drop separation in LIFT printing' (Filing no.:PN2313);
'Multiple simultaneous drop sizes in Proximity LIFT printing' (Filing no.:
PN2321);
'Self cooling operation in thermally activated print heads' (Filing no.:
PN2322); and
'Thermal Viscosity Reduction LIFT printing' (Filing no.: PN2323).

A simplified schematic diagram of one preferred printing system according to the invention appears in Figure1(a).

An image source 52 may be raster image data from a scanner or computer, or outline image data in the form of a page description language (PDL), or other forms of digital image representation. This image data is converted to a pixel-mapped page image by the image processing system 53. This may be a raster image processor (RIP) in the case of PDL image data, or may be pixel image manipulation in the case of raster image data. Continuous tone data produced by the image processing unit 53 is halftoned. Halftoning is performed by the Digital
Halftoning unit 54. Halftoned bitmap image data is stored in the image memory 72.

Depending upon the printer and system configuration, the image memory 72 may be a full page memory, or a band memory. Heater control circuits 71 read data from the image memory 72 and apply time-varying electrical pulses to the nozzle heaters (103 in figure1(b)) that are part of the print head 50. These pulses are applied at an appropriate time, and to the appropriate nozzle, so that selected drops will form spots on the recording medium 51 in the appropriate position designated by the data in the image memory 72.

The recording medium 51 is moved relative to the head 50 by a paper transport system 65, which is electronically controlled by a paper transport control system 66, which in turn is controlled by a microcontroller 315. The paper transport system shown in figure1(a) is schematic only, and many different mechanical configurations are possible. In the case of pagewidth print heads, it is most convenient to move the recording medium 51 past a stationary head 50.

However, in the case of scanning print systems, it is usually most convenient to move the head 50 along one axis (the sub-scanning direction) and the recording medium 51 along the orthogonal axis (the main scanning direction), in a relative raster motion. The microcontroller 315 may also control the ink pressure regulator 63 and the heater control circuits 71.

For printing using surface tension reduction, ink is contained in an ink reservoir 64 under pressure. In the quiescent state (with no ink drop ejected), the ink pressure is insufficient to overcome the ink surface tension and eject a drop.

A constant ink pressure can be achieved by applying pressure to the ink reservoir 64 under the control of an ink pressure regulator 63. Alternatively, for larger printing systems, the ink pressure can be very accurately

generated and controlled by situating the top surface of the ink in the reservoir 64 an appropriate distance above the head 50. This ink level can be regulated by a simple float valve (not shown).

For printing using viscosity reduction, ink is contained in an ink reservoir 64 under pressure, and the ink pressure is caused to oscillate. The means of producing this oscillation may be a piezoelectric actuator mounted in the ink channels (not shown).

When properly arranged with the drop separation means, selected drops proceed to form spots on the recording medium 51, while unselected drops remain part of the body of ink.

The ink is distributed to the back surface of the head 50 by an ink channel device 75. The ink preferably flows through slots andlor holes etched through the silicon substrate of the head 50 to the front surface, where the nozzles and actuators are situated. In the case of thermal selection, the nozzle actuators are electrothermal heaters.

In some types of printers according to the invention, an external field 74 is required to ensure that the selected drop separates from the body of the ink and moves towards the recording medium 51. A convenient external field 74 is a constant electric field, as the ink is easily made to be electrically conductive. In this case, the paper guide or platen 67 can be made of electrically conductive material and used as one electrode generating the electric field. The other electrode can be the head 50 itself. Another embodiment uses proximity of the print medium as a means of discriminating between selected drops and unselected drops.

For small drop sizes gravitational force on the ink drop is very small; approximately104 of the surface tension forces, so gravity can be ignored in most cases. This allows the print head 50 and recording medium 51 to be oriented in any direction in relation to the local gravitational field. This is an important requirement for portable printers.

Figure1 (b) is a detail enlargement of a cross section of a single microscopic nozzle tip embodiment of the invention, fabricated using a modified
CMOS process. The nozzle is etched in a substrate 101, which may be silicon, glass, metal, or any other suitable material. If substrates which are not semiconductor materials are used, a semiconducting material (such as amorphous silicon) may be deposited on the substrate, and integrated drive transistors and data distribution circuitry may be formed in the surface semiconducting layer. Single crystal silicon (SCS) substrates have several advantages, including: 1) High performance drive transistors and other circuitry can be fabricated in
SCS; 2) Print heads can be fabricated in existing facilities (fabs) using standard VLSI processing equipment; 3) SCS has high mechanical strength and rigidity; and 4) SCS has a high thermal conductivity.

In this example, the nozzle is of cylindrical form, with the heater 103 forming an annulus. The nozzle tip 104 is formed from silicon dioxide layers 102 deposited during the fabrication of the CMOS drive circuitry. The nozzle tip is passivated with silicon nitride. The protruding nozzle tip controls the contact point of the pressurized ink 100 on the print head surface. The print head surface is also hydrophobized to prevent accidental spread of ink across the front of the print head.

Many other configurations of nozzles are possible, and nozzle embodiments of the invention may vary in shape, dimensions, and materials used.

Monolithic nozzles etched from the substrate upon which the heater and drive electronics are formed have the advantage of not requiring an orifice plate. The elimination of the orifice plate has significant cost savings in manufacture and assembly. Recent methods for eliminating orifice plates include the use of 'vortex' actuators such as those described in Domoto et al US Pat. No. 4,580,158, 1986, assigned to Xerox, and Miller et al US Pat. No. 5,371,527, 1994 assigned to
Hewlett-Packard. These, however are complex to actuate, and difficult to fabricate.

The preferred method for elimination of orifice plates for print heads of the invention is incorporation of the orifice into the actuator substrate.

This type of nozzle may be used for print heads using various techniques for drop separation.

Operation with Electrostatic Drop Separation

As a first example, operation using thermal reduction of surface tension and electrostatic drop separation is shown in figure 2.

Figure 2 shows the results of energy transport and fluid dynamic simulations performed using FIDAP, a commercial fluid dynamic simulation software package available from Fluid Dynamics Inc., of Illinois, USA. This simulation is of a thermal drop selection nozzle embodiment with a diameter of 8 pin, at an ambient temperature of30"C. The total energy applied to the heater is 276nJ, applied as 69 pulses of 4 nJ each. The ink pressure is 10 kPa above ambient air pressure, and the ink viscosity at30"C is 1.84 cPs. The ink is water based, and includes a sol of 0.1% palmitic acid to achieve an enhanced decrease in surface tension with increasing temperature. A cross section of the nozzle tip from the central axis of the nozzle to a radial distance of 40pin is shown.Heat flow in the various materials of the nozzle, including silicon, silicon nitride, amorphous silicon dioxide, crystalline silicon dioxide, and water based ink are simulated using the respective densities, heat capacities, and thermal conductivities of the materials. The time step of the simulation is 0.1Rs.

Figure 2(a) shows a quiescent state, just before the heater is actuated. An equilibrium is created whereby no ink escapes the nozzle in the quiescent state by ensuring that the ink pressure plus external electrostatic field is insufficient to overcome the surface tension of the ink at the ambient temperature.

In the quiescent state, the meniscus of the ink does not protrude significantly from the print head surface, so the electrostatic field is not significantly concentrated at the meniscus.

Figure 2(b) shows thermal contours at5"C intervals 5s after the start of the heater energizing pulse. When the heater is energized, the ink in contact with the nozzle tip is rapidly heated. The reduction in surface tension causes the heated portion of the meniscus to rapidly expand relative to the cool ink meniscus.

This drives a convective flow which rapidly transports this heat over part of the free surface of the ink at the nozzle tip. It is necessary for the heat to be distributed over the ink surface, and not just where the ink is in contact with the heater. This is because viscous drag against the solid heater prevents the ink directly in contact with the heater from moving.

Figure 2(c) shows thermal contours at5"C intervals 10Rs after the start of the heater energizing pulse. The increase in temperature causes a decrease in surface tension, disturbing the equilibrium of forces. As the entire meniscus has been heated, the ink begins to flow.

Figure 2(d) shows thermal contours at5"C intervals 20gs after the start of the heater energizing pulse. The ink pressure has caused the ink to flow to a new meniscus position, which protrudes from the print head. The electrostatic field becomes concentrated by the protruding conductive ink drop.

Figure 2(e) shows thermal contours at5"C intervals 30is after the start of the heater energizing pulse, which is also 6Rs after the end of the heater pulse, as the heater pulse duration is 24Rs. The nozzle tip has rapidly cooled due to conduction through the oxide layers, and conduction into the flowing ink. The nozzle tip is effectively 'water cooled' by the ink. Electrostatic attraction causes the ink drop to begin to accelerate towards the recording medium. Were the heater pulse significantly shorter (less than 16Ls in this case) the ink would not accelerate towards the print medium, but would instead return to the nozzle.

Figure 2(f) shows thermal contours at5"C intervals 26Rs after the end of the heater pulse. The temperature at the nozzle tip is now less than5"C above ambient temperature. This causes an increase in surface tension around the nozzle tip. When the rate at which the ink is drawn from the nozzle exceeds the viscously limited rate of ink flow through the nozzle, the ink in the region of the nozzle tip 'necks', and the selected drop separates from the body of ink. The selected drop then travels to the recording medium under the influence of the external electrostatic field. The meniscus of the ink at the nozzle tip then returns to its quiescent position, ready for the next heat pulse to select the next ink drop. One ink drop is selected, separated and forms a spot on the recording medium for each heat pulse.As the heat pulses are electrically controlled, drop on demand ink jet operation can be achieved.

Figure 3(a) shows successive meniscus positions during the drop selection cycle at 5Rs intervals, starting at the beginning of the heater energizing pulse.

Figure 3(b) is a graph of meniscus position versus time, showing the movement of the point at the centre of the meniscus. The heater pulse starts 10Rs into the simulation.

Figure 3(c) shows the resultant curve of temperature with respect to time at various points in the nozzle. The vertical axis of the graph is temperature, in units of100"C. The horizontal axis of the graph is time, in units of 10Fs. The temperature curve shown in figure 3(b) was calculated by FIDAP, using 0.1Rs time steps. The local ambient temperature is 30 degrees C. Temperature histories at three points are shown:
A - Nozzle tip: This shows the temperature history at the circle of contact between the passivation layer, the ink, and air.

B - Meniscus midpoint: This is at a circle on the ink meniscus midway between the nozzle tip and the centre of the meniscus.

C - Chip surface: This is at a point on the print head surface 20Rm from the centre of the nozzle. The temperature only rises a few degrees. This indicates that active circuitry can be located very close to the nozzles without experiencing performance or lifetime degradation due to elevated temperatures.

Figure 3(e) shows the power applied to the heater. Optimum operation requires a sharp rise in temperature at the start of the heater pulse, a maintenance of the temperature a little below the boiling point of the ink for the duration of the pulse, and a rapid fall in temperature at the end of the pulse. To achieve this, the average energy applied to the heater is varied over the duration of the pulse. In this case, the variation is achieved by pulse frequency modulation of 0.1Rs sub-pulses, each with an energy of 4 nJ. The peak power applied to the heater is 40 mW, and the average power over the duration of the heater pulse is 11.5 mW. The sub-pulse frequency in this case is 5 Mhz. This can readily be varied without significantly affecting the operation of the print head.A higher sub-pulse frequency allowsflier control over the power applied to the heater. A sub-pulse frequency of 13.5 Mhz is suitable, as this frequency is also suitable for minimizing the effect of radio frequency interference (RFI).

Ink
Figure 3(d) shows the measured effect of temperature on the surface tension of various aqueous preparations containing the following additives: 1)0.1 % sol of Stearic Acid 2)0.1% sol of Palmitic acid 3) 0.1% solution of Pluronic 10R5 (trade mark of BASF) 4)0.1% solution of Pluronic L35 (trade mark of BASF) 5) 0.1% solution of PluronicL44 (trade mark of BASF)
Inks suitable for printing systems of the present invention are described in the following Australian patent specifications, the disclosure of which are hereby incorporated by reference:
'Ink composition based on a microemulsion' (Filing no.: PN5223, filed on 6 September 1995);
'Ink composition containing surfactant sol' (Filing no.:PN5224, filed on 6 September 1995);
'Ink composition for DOD printers with Krafft point near the drop selection temperature sol' (Filing no.: PN6240, filed on 30 October 1995);
'Dye and pigment in a microemulsion based ink' (Filing no.: PN6241, filed on 30 October 1995);
OperationUsmp Reduction ofVlscositv
As a second example, operation of an embodiment using thermal reduction of viscosity and proximity drop separation, in combination with hot melt ink, is as follows. Prior to operation of the printer, solid ink is melted in the reservoir 64. The reservoir, ink passage to the print head, ink channels 75, and print head 50 are maintained at a temperature at which the ink 100 is liquid, but exhibits a relatively high viscosity (for example, approximately 100 cP).The Ink 100 is retained in the nozzle by the surface tension of the ink. The ink 100 is formulated so that the viscosity of the ink reduces with increasing temperature. The ink pressure oscillates at a frequency which is an integral multiple of the drop ejection frequency from the nozzle. The ink pressure oscillation causes oscillations of the ink meniscus at the nozzle tips, but this oscillation is small due to the high ink viscosity. At the normal operating temperature, these oscillations are of insufficient amplitude to result in drop separation. When the heater 103 is energized, the ink forming the selected drop is heated, causing a reduction in viscosity to a value which is preferably less than 5 cP. The reduced viscosity results in the ink meniscus moving further during the high pressure part of the ink pressure cycle.The recording medium 51 is arranged sufficiently close to the print head 50 so that the selected drops contact the recording medium 51, but sufficiently far away that the unselected drops do not contact the recording medium 51. Upon contact with the recording medium 51, part of the selected drop freezes, and attaches to the recording medium.

As the ink pressure falls, ink begins to move back into the nozzle. The body of ink separates from the ink which is frozen onto the recording medium. The meniscus of the ink 100 at the nozzle tip then returns to low amplitude oscillation. The viscosity of the ink increases to its quiescent level as remaining heat is dissipated to the bulk ink and print head. One ink drop is selected, separated and forms a spot on the recording medium 51 for each heat pulse. As the heat pulses are electrically controlled, drop on demand ink jet operation can

be achieved.

Manufactunne of Pnnt Heads
Manufacturing processes for monolithic print heads in accordance with the present invention are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:
'A monolithic LIFT printing head' (Filing no.: PN2301);
'A manufacturing process for monolithic LIFT printing heads' (Filing no.: PN2302);
'A self-aligned heater design for LIFT print heads' (Filing no.: PN2303);
'Integrated four color LIFT print heads' (Filing no.: PN2304);
'Power requirement reduction in monolithic LIFT printing heads' (Filing no.: PN2305);
'A manufacturing process for monolithic LIFT print heads using anisotropic wet etching' (Filing no.:PN2306);
'Nozzle placement in monolithic drop-on-demand print heads' (Filing no.: PN2307);
'Heater structure for monolithic LIFT print heads' (Filing no.: PN2346);
'Power supply connection for monolithic LIFT print heads' (Filing no.: PN2347);
'External connections for Proximity LIFT print heads' (Filing no.: PN2348); and 'A self-aligned manufacturing process for monolithic LIFT I print heads' (Filing no.: PN2349); and
'CMOS process compatible fabrication of LIFT print heads' (Filing no.: PN5222, 6 September 1995).

'A manufacturing process for LIFT print heads with nozzle rim heaters' (Filing no.: PN6238, 30 October 1995);
'A modular LIFT print head' (Filing no.: PN6237, 30 October 1995);
'Method of increasing packing density of printing nozzles' (Filing no.: PN6236, 30 October 1995); and
'Nozzle dispersion for reduced electrostatic interaction between simultaneously printed droplets' (Filing no.: PN6239, 30 October 1995).

Control ofPnnt Heads
Means of providing page image data and controlling heater temperature in print heads of the present invention is described in the following
Australian patent specifications filed on12April1995, the disclosure of which are hereby incorporated by reference:
'Integrated drive circuitry in LIFT print heads' (Filing no.: PN2295);
'A nozzle clearing procedure for Liquid Ink Fault Tolerant(LIFT) printing' (Filing no.: PN2294);
'Heater power compensation for temperature in LIFT printing systems' (Filing no.: PN2314);
'Heater power compensation for thermal lag in LIFT printing systems' (Filing no.: PN2315);
'Heater power compensation for print density in LIFT printing systems' (Filing no.:PN2316);
'Accurate control of temperature pulses in printing heads' (Filing no.:Pun2317);
'Data distribution in monolithic LIFT print heads' (Filing no.: PN2318);
'Page image and fault tolerance routing device for LIFT printing systems' (Filing no.: PN2319); and
'A removable pressurized liquid ink cartridge for LIFT printers' (Filing no.: PN2320).

Image Processmg forPrint Heads
An objective of printing systems according to the invention is to attain a print quality which is equal to that which people are accustomed to in quality color publications printed using offset printing. This can be achieved using a print resolution of approximately 1,600 dpi. However, 1,600 dpi printing is difficult and expensive to achieve. Similar results can be achieved using 800 dpi printing, with 2 bits per pixel for cyan and magenta, and one bit per pixel for yellow and black This color model is herein called CC'MM'YK. Where high quality monochrome image printing is also required, two bits per pixel can also be used for black. This color model is herein called CC'MM'YKK'.Color models, halftoning, data compression, and real-time expansion systems suitable for use in systems of this invention and other printing systems are described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:
'Four level ink set for bi-level color printing' (Filing no.: PN2339);
'Compression system for page images' (Filing no.: PN2340);
'Real-time expansion apparatus for compressed page images' (Filing no.:

PN2341); and
'High capacity compressed document image storage for digital color printers' (Filing no.: PN2342);
'Improving JPEG compression in the presence of text' (Filing no.:
PN2343);
'An expansion and halftoning device for compressed page images' (Filing no.: PN2344); and
'Improvements in image halftoning' (Filing no.: PN2345).

Applications UsmgPnnt Heads Accordmg to this Invention
Printing apparatus and methods of this invention are suitable for a wide range of applications, including (but
not limited to) the following: color and monochrome office printing, short run digital printing, high speed digital
printing, process color printing, spot color printing, offset press supplemental printing, low cost printers using
scanning print heads, high speed printers using pagewidth print heads, portable color and monochrome
printers, color and monochrome copiers, color and monochrome facsimile machines, combined printer,
facsimile and copying machines, label printing, large format plotters, photographic duplication, printers for
digital photographic processing, portable printers incorporated into digital 'instant' cameras, video printing,
printing of PhotoCD images, portable printers for 'Personal
Digital Assistants', wallpaper printing, indoor sign printing, billboard printing, and fabric printing.

Printing systems based on this invention are described in the following Australian patent specifications filed
on 12 April 1995, the disclosure of which are hereby incorporated by reference:
'A high speed color office printer with a high capacity digital page image store' (Filing no.: PN2329);
'A short run digital color printer with a high capacity digital page image store' (Filing no.: PN2330);
'A digital color printing press using LIFT printing technology' (Filing no.:
PN2331);
'A modular digital printing press' (Filing no.: PN2332);
'A high speed digital fabric printer' (Filing no.: PN2333);
'A color photograph copying system' (Filing no.:PN2334);
'A high speed color photocopier using a LIFT printing system' (Filing no.:
PN2335);
'A portable color photocopier using LIFT printing technology' (Filing no.:
PN2336);
'A photograph processing system using LIFT printing technology' (Filing no.: PN2337);
'A plain paper facsimile machine using a LIFT printing system' (Filing no.: PN2338);
'A PhotoCD system with integrated printer' (Filing no.: PN2293);
'A color plotter using LIFT printing technology' (Filing no.: PN2291);
'A notebook computer with integrated LIFT color printing system' (Filing no.: PN2292);
'A portable printer using a LIFT printing system' (Filing no.: PN2300);
'Fax machine with on-line database interrogation and customized magazine printing' (Filing no.: PN2299);
'Miniature portable color printer' (Filing no.: PN2298);
'A color video printer using a LIFT printing system' (Filing no.:PN2296); and
'An integrated printer, copier, scanner, and facsimile using a LIFT printing system' (Filing no.: PN2297)
Compensation of Pnnt Heads for EnvlronmentalConditions
It is desirable that drop on demand printing systems have consistent and predictable ink drop size and
position. Unwanted variation in ink drop size and position causes variations in the optical density of the
resultant print, reducing the perceived print quality. These variations should be kept to a small proportion of
the nominal ink drop volume and pixel spacing respectively. Many environmental variables can be
compensated to reduce their effect to insignificant levels. Active compensation of some factors can be
achieved by varying the power applied to the nozzle heaters.

An optimum temperature profile for one print head embodiment involves an instantaneous raising of the
active region of the nozzle tip to the ejection temperature, maintenance of this region at the ejection
temperature for the duration of the pulse, and instantaneous cooling of the region to the ambient
temperature.

This optimum is not achievable due to the stored heat capacities and thermalconductivities of the various
materials used in the fabrication of the nozzles in accordance with the invention. However, improved
performance can be achieved by shaping the power pulse using curves which can be derived by iterative
refinement of finite element simulation of the print head. The power applied to the heater can be varied in
time by various techniques, including, but not limited to: 1) Varying the voltage applied to the heater 2)
Modulating the width of a series of short pulses (PWM) 3) Modulating the frequency of a series of short
pulses (PFM)

To obtain accurate results, a transient fluid dynamic simulation with free surface modeling is required, as convection in the ink, and ink flow, significantly affect the temperature achieved with a specific power curve.

By the incorporation of appropriate digital circuitry on the print head substrate, it is practical to individually control the power applied to each nozzle.

One way to achieve this is by 'broadcasting' a variety of different digital pulse trains across the print head chip, and selecting the appropriate pulse train for each nozzle using multiplexing circuits.

An example of the environmental factors which may be compensated for is listed in the table "Compensation for environmental factors". This table identifies which environmental factors are best compensated globally (for the entire print head), per chip (for each chip in a composite multi-chip print head), and per nozzle.

Compensation for environmental factors
EMI28.1

<tb> Factor <SEP> Scope <SEP> Sensing <SEP> or <SEP> user <SEP> Compensation
<tb> compensated <SEP> control <SEP> method <SEP> mechanism
<tb> Ambient <SEP> Global <SEP> Temperature <SEP> sensor <SEP> Power <SEP> supply <SEP> voltage
<tb> Temperature <SEP> mounted <SEP> on <SEP> print <SEP> head <SEP> or <SEP> lobal <SEP> PFM <SEP> patterns
<tb> Power <SEP> supply <SEP> Global <SEP> Predictive <SEP> active <SEP> Power <SEP> supply <SEP> voltage
<tb> voltage <SEP> fluctuation <SEP> nozzle <SEP> count <SEP> based <SEP> on <SEP> or <SEP> global <SEP> PFM <SEP> patterns
<tb> with <SEP> number <SEP> of <SEP> print <SEP> data
<tb> active <SEP> nozzles
<tb> Local <SEP> heat <SEP> build- <SEP> Per <SEP> Predictive <SEP> active <SEP> Selection <SEP> of
<tb> <SEP> up <SEP> with <SEP> successive <SEP> nozzle <SEP> nozzle <SEP> count <SEP> based <SEP> on <SEP> appropriate <SEP> PFM
<tb> <SEP> nozzle <SEP> actuation <SEP> print <SEP> data <SEP> pattern <SEP> for <SEP> each <SEP> printed
<tb> <SEP> Drop <SEP> size <SEP> control <SEP> Per <SEP> Image <SEP> data <SEP> Selection <SEP> of
<tb> <SEP> for <SEP> multiple <SEP> bits <SEP> nozzle <SEP> appropriate <SEP> PFM
<tb> <SEP> per <SEP> pixel <SEP> pattern <SEP> for <SEP> each <SEP> printed
<tb> <SEP> drop
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<tb> <SEP> wafers <SEP> print <SEP> head
<tb>
EMI29.1

<tb> Heater <SEP> resistivity <SEP> Per <SEP> Factory <SEP> measurement, <SEP> Global <SEP> PFM <SEP> patterns
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<tb> intensity <SEP> electrostatic
<tb> adjustment <SEP> acceleration <SEP> voltage, <SEP> or
<tb> <SEP> ink <SEP> pressure
<tb> Ink <SEP> surface <SEP> tension <SEP> Global <SEP> Ink <SEP> cartridge <SEP> sensor <SEP> or <SEP> Global <SEP> PFM <SEP> patterns

<tb> reduction <SEP> method <SEP> user <SEP> selection
<tb> and <SEP> threshold
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Global <SEP> PFM <SEP> patterns
<tb> <SEP> user <SEP> selection <SEP> and/or <SEP> clock <SEP> rate
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<SEP> or <SEP> Global <SEP> PFM <SEP> patterns
<tb> concentration <SEP> user <SEP> selection
<tb> Ink <SEP> response <SEP> time <SEP> Global <SEP> Ink <SEP> cartridge <SEP> sensor <SEP> or
<SEP> Global <SEP> PFM <SEP> patterns
<tb> <SEP> user <SEP> selection
<tb>
Most applications will not require compensation for all of these variables. Some variables have a minor
effect, and compensation is only necessary where very high image quality is required.

Pnnt head dnvecircuits
Figure 4 is a block schematic diagram showing electronic operation of an example head driver circuit in
accordance with this invention. This control circuit uses analog modulation of the power supply voltage
applied to the print head to achieve heater power modulation, and does not have individual control of the
power applied to each nozzle. Figure 4 shows a block diagram for a system using an 800 dpi pagewidth print
head which prints process color using the CC'MM'YK color model. The print head 50 has a total of 79,488
nozzles, with 39,744 main nozzles and 39,744 redundant nozzles. The main and redundant nozzles are
divided into six colors, and each color is divided into 8 drive phases.Each drive phase has a shift register
which converts the serial data from a head control ASIC 400 into parallel data for enabling heater drive
circuits. There is a total of 96 shift registers, each providing data for 828 nozzles. Each shift register is
composed of 828 shift register stages 217, the outputs of which are logically anded with phase enable signal
by a nand gate 215. The output of the nand gate 215 drives an inverting buffer 216, which in turn controls the
drive transistor 201.The drive transistor 201 actuates the electrothermal heater 200, which may be a heater
103 as shown in figure1(b). To maintain the shifted data valid during the enable pulse, the clock to the shift
register is stopped the enable pulse is active by a clock stopper 218, which is shown as a single gate for
clarity, but is preferably any of a range of well known glitch free clock control circuits. Stopping the clock of
the shift register removes the requirement for a parallel data latch in the print head, but adds some
complexity to the control circuits in the Head Control ASIC 400. Data is routed to either the main nozzles or
the redundant nozzles by the data router 219 depending on the state of the appropriate signal of the fault
status bus.

The print head shown in figure 4 is simplified, and does not show various means of improving manufacturing
yield, such as block fault tolerance.

Drive circuits for different configurations of print head can readily be derived from the apparatus disclosed
herein.

Digital information representing patterns of dots to be printed on the recording medium is stored in the Page
or Band memory 1513, which may be the same as the Image memory 72 in figure1(a). Data in 32 bit words
representing dots of one color is read from the Page or Band memory 1513 using addresses selected by the
address mux 417 and control signals generated by the Memory Interface 418.

These addresses are generated by Address generators 411, which forms part of the 'Per color circuits' 410,
for which there is one for each of the six color components.

The addresses are generated based on the positions of the nozzles in relation to the print medium. As the
relative position of the nozzles may be different for different print heads, the Address generators 411 are
preferably made programmable. The
Address generators 411 normally generate the address corresponding to the position of the main nozzles.
However, when faulty nozzles are present, locations of blocks of nozzles containing faults can be marked in
the Fault Map RAM 412. The
Fault Map RAM 412 is read as the page is printed. If the memory indicates a fault in the block of nozzles, the
address is altered so that the Address generators 411 generate the address corresponding to the position of
the redundant nozzles. Data read from the Page or Band memory 1513 is latched by the latch 413 and
converted to four sequential bytes by the multiplexer 414.Timing of these bytes is adjusted to match that of

data representing other colors by the FIFO 415. This data is then buffered by the buffer 430 to form the 48 bit main data bus to the print head 50.

The data is buffered as the print head may be located a relatively long distance from the head control ASIC. Data from the Fault Map RAM 412 also forms the input to the FIFO 416. The timing of this data is matched to the data output of the FIFO 415, and buffered by the buffer 431 to form the fault status bus.

The programmable power supply 320 provides power for the head 50. The voltage of the power supply 320 is controlled by the DAC 313, which is part of a RAM and DAC combination (RAMDAC) 316. The RAMDAC 316 contains a dual port RAM 317. The contents of the dual port RAM 317 are programmed by the Microcontroller 315. Temperature is compensated by changing the contents of the dual port RAM 317. These values are calculated by the microcontroller 315 based on temperature sensed by a thermal sensor 300. The thermal sensor 300 signal connects to the Analog to Digital Converter (ADC) 311.

The ADC 311 is preferably incorporated in the Microcontroller 315.

The Head Control ASIC 400 contains control circuits for thermal lag compensation and print density. Thermal lag compensation requires that the power supply voltage to the head 50 is a rapidly time-varying voltage which is synchronized with the enable pulse for the heater. This is achieved by programming the programmable power supply 320 to produce this voltage. An analog time varying programming voltage is produced by the DAC 313 based upon data read from the dual port RAM 317. The data is read according to an address produced by the counter 403. The counter 403 produces one complete cycle of addresses during the period of one enable pulse. This synchronization is ensured, as the counter 403 is clocked by the system clock 408, and the top count of the counter 403 is used to clock the enable counter 404. The count from the enable counter 404 is then decoded by the decoder 405 and buffered by the buffer 432 to produce the enable pulses for the head 50. The counter 403 may include a prescaler if the number of states in the count is less than the number of clock periods in one enable pulse.

Sixteen voltage states are adequate to accurately compensate for the heater thermal lag. These sixteen states can be specified by using a four bit connection between the counter 403 and the dual port RAM 317. However, these sixteen states may not be linearly spaced in time. To allow non-linear timing of these states the counter 403 may also include a ROM or other device which causes the counter 403 to count in a non-linear fashion. Alternatively, fewer than sixteen states may be used.

For print density compensation, the printing density is detected by counting the number of pixels to which a drop is to be printed ('on' pixels) in each enable period. The 'on' pixels are counted by the On pixel counters 402. There is one On pixel counter 402 for each of the eight enable phases. The number of enable phases in a print head in accordance with the invention depend upon the specific design. Four, eight, and sixteen are convenient numbers, though there is no requirement that the number of enable phases is a power of two. The On Pixel
Counters 402 can be composed of combinatorial logic pixel counters 420 which determine how many bits in a nibble of data are on. This number is then accumulated by the adder 421 and accumulator 422. A latch 423 holds the accumulated value valid for the duration of the enable pulse. The multiplexer 401 selects the output of the latch 423 which corresponds to the current enable phase, as determined by the enable counter 404. The output of the multiplexer 401 forms part of the address of the dual port RAM 317. An exact count of the number of 'on' pixels is not necessary, and the most significant four bits of this count are adequate.

Combining the four bits of thermal lag compensation address and the four bits of print density compensation address means that the dual port RAM 317 has an 8 bit address. This means that the dual port RAM 317 contains 256 numbers, which are in a two dimensional array. These two dimensions are time (for thermal lag compensation) and print density. A third dimension - temperature - can be included. As the ambient temperature of the head varies only slowly, the microcontroller 315 has sufficient time to calculate a matrix of 256 numbers compensating for thermal lag and print density at the current temperature.

Periodically (for example, a few times a second), the microcontroller senses the current head temperature and calculates this matrix.

The clock to the print head 50 is generated from the system clock 408 by the Head clock generator 407, and buffered by the buffer 406. To facilitate testing of the Head control ASIC, JTAG test circuits 499 may be included.

Companson with thermalmk lettechnologv
The table "Comparison between Thermal ink jet and Present
Invention" compares the aspects of printing in accordance with the present invention with thermal ink jet
printing technology.

A direct comparison is made between the present invention and thermal ink jet technology because both are
drop on demand systems which operate using thermal actuators and liquid ink. Although they may appear
similar, the two technologies operate on different principles.

Thermal ink jet printers use the following fundamental operating principle. A thermal impulse caused by
electrical resistance heating results in the explosive formation of a bubble in liquid ink. Rapid and consistent
bubble formation can be achieved by superheating the ink, so that sufficient heat is transferred to the ink
before bubble nucleation is complete. For water based ink, ink temperatures of approximately280"C to400"C
are required. The bubble formation causes a pressure wave which forces a drop of ink from the aperture with
high velocity. The bubble then collapses, drawing ink from the ink reservoir to re-fill the nozzle.

Thermal ink jet printing has been highly successful commercially due to the high nozzle packing density and
the use of well established integrated circuit manufacturing techniques. However, thermal ink jet printing
technology faces significant technical problems including multi-part precision fabrication, device yield, image
resolution, 'pepper' noise, printing speed, drive transistor power, waste power dissipation, satellite drop
formation, thermal stress, differential thermal expansion, kogation, cavitation, rectified diffusion, and
difficulties in ink formulation.

Printing in accordance with the present invention has many of the advantages of thermal ink jet printing, and
completely or substantially eliminates many of the inherent problems of thermal ink jet technology.

Comparison between Thermal ink jet and Present Invention
EMI34.1

<tb> <SEP> Thermal <SEP> Ink-Jet <SEP> Present <SEP> Invention
<tb> Drop <SEP> selection <SEP> Drop <SEP> ejected <SEP> by <SEP> pressure <SEP> Choice <SEP>
of <SEP> surface <SEP> tension <SEP> or
<tb> mechanism <SEP> wave <SEP> caused <SEP> by <SEP> thermally <SEP> viscosity <SEP>
reduction
<tb> <SEP> induced <SEP> bubble <SEP> mechanisms
<tb> Drop <SEP> separation <SEP> Same <SEP> as <SEP> drop <SEP> selection <SEP> Choice <SEP>
of <SEP> proximity,
<tb> mechanism <SEP> mechanism <SEP> electrostatic, <SEP> magnetic, <SEP> and
<tb> <SEP> other <SEP> methods
<tb> Basic <SEP> ink <SEP> carrier <SEP> Water <SEP> Water, <SEP> microemulsion,
<tb> <SEP> alcohol, <SEP> 1 <SEP> color <SEP> hot <SEP> melt
<tb> Head <SEP> construction <SEP> Precision <SEP> assembly <SEP> of <SEP> Monolithic
<tb> <SEP> nozzle <SEP> plate, <SEP> ink <SEP> channel,
<tb> <SEP> and <SEP> substrate
<tb> Per <SEP> copy <SEP> printing <SEP> Very <SEP> high <SEP> due <SEP> to <SEP> limited <SEP>
Can <SEP> be <SEP> low <SEP> due <SEP> to
<tb> cost <SEP> print <SEP> head <SEP> life <SEP> and <SEP> permanent <SEP> print <SEP> heads
<SEP> and
<tb> <SEP> expensive <SEP> inks <SEP> wide <SEP> range <SEP> of <SEP> possible <SEP> inks
<tb> Satellite <SEP> drop <SEP> Significant <SEP> problem <SEP> which <SEP> No <SEP> satellite
<SEP> drop <SEP> formation
<tb> formation <SEP> degrades <SEP> image <SEP> quality
<tb> Operating <SEP> ink <SEP> 280"C <SEP> to <SEP> 400 C <SEP> (high <SEP> Approx.<SEP> 70"C
<SEP> (depends
<tb> temperature <SEP> temperature <SEP> limits <SEP> dye <SEP> use <SEP> upon <SEP> ink <SEP>
formulation)
<tb> <SEP> and <SEP> ink <SEP> formulation)
<tb> Peak <SEP> heater <SEP> 400"C <SEP> to <SEP> 1,000 C <SEP> (high <SEP> Approx.<SEP>
1300C <SEP>
<tb> temperature <SEP> temperature <SEP> reduces <SEP> device

<tb> <SEP> life)
<tb>Cavitation <SEP> (heater <SEP> Serious <SEP> problem <SEP> iimiting <SEP> None <SEP> (no <SEP> bubbles <SEP> are <SEP>
<tb> erosion <SEP> by <SEP> bubble <SEP> head <SEP> life <SEP> formed)
<tb> collapse)
<tb> Kogation <SEP> (coating <SEP> Serious <SEP> problem <SEP> limiting <SEP> None <SEP> (water <SEP> based <SEP> ink
<tb> of <SEP> heater <SEP> by <SEP> ink <SEP> head <SEP> life <SEP> and <SEP> ink <SEP> temperature <SEP> does <SEP> not <SEP> exceed
<tb> ash) <SEP> formulation <SEP> 100 C) <SEP>
<tb> Rectified <SEP> diffusion <SEP> Serious <SEP> problem <SEP> limiting <SEP> Does <SEP> not <SEP> occur <SEP> as <SEP> the <SEP> ink
<tb> (formation <SEP> of <SEP> ink <SEP> ink <SEP> formulation <SEP> pressure <SEP> does <SEP> not <SEP> go
<tb> bubbles <SEP> due <SEP> to <SEP> negative
<tb> pressure <SEP> cycles)
<tb> Resonance <SEP> Serious <SEP> problem <SEP> limiting <SEP> Very <SEP> small <SEP> effect <SEP> as
<tb> <SEP> nozzle <SEP> design <SEP> and <SEP> pressure <SEP> waves <SEP> are <SEP> small
<tb> <SEP> repetition <SEP> rate
<tb> Practical <SEP> resolution <SEP> Approx. <SEP> 800 <SEP> dpi <SEP> max. <SEP> Approx. <SEP> 1,600 <SEP> dpi <SEP> max.
<tb>

Self-cooling <SEP> No <SEP> (high <SEP> energy <SEP> required) <SEP> Yes: <SEP> printed <SEP> ink <SEP> carries
<tb>generation <SEP> awa <SEP> droop <SEP> selection <SEP> energy
<tb> Drop <SEP> ejection <SEP> High <SEP> (approx. <SEP> 10 <SEP> m/sec) <SEP> Low <SEP> (approx. <SEP> 1 <SEP> m/sec <SEP>)
<tb> velocity
<tb>
EMI35.1

<tb> Crosstalk <SEP> Serious <SEP> problem <SEP> requiring <SEP> Low <SEP> velocities <SEP> and
<tb> <SEP> careful <SEP> acoustic <SEP> design, <SEP> pressures <SEP> associated <SEP> with
<tb> <SEP> which <SEP> limits <SEP> nozzle <SEP> refill <SEP> drop <SEP> ejection <SEP> make <SEP> crosstalk
<tb> <SEP> rate. <SEP> very <SEP> small.
<tb>

Operating <SEP> thermal <SEP> Serious <SEP> problem <SEP> limiting <SEP> Low: <SEP> maximum <SEP> temperature
<tb> stress <SEP> print-head <SEP> life. <SEP> increase <SEP> approx. <SEP> 90"C <SEP> at
<tb> <SEP> centre <SEP> of <SEP> heater.
<tb>

Manufacturing <SEP> Serious <SEP> problem <SEP> limiting <SEP> Same <SEP> as <SEP> standard <SEP> CMOS
<tb> thermal <SEP> stress <SEP> print-head <SEP> size. <SEP> manufacturing <SEP> process.
<tb>

Drop <SEP> selection <SEP> Approx. <SEP> 20 <SEP> pJ <SEP> Approx. <SEP> 270 <SEP> nJ
<tb>energy <SEP>
<tb> Heater <SEP> pulse <SEP> period <SEP> Approx. <SEP> 2-3 <SEP> s <SEP> Approx. <SEP> 15-30
<tb> Average <SEP> heater <SEP> Approx. <SEP> 8 <SEP> Watts <SEP> per <SEP> Approx. <SEP> 12 <SEP> mW <SEP> per <SEP> heater.
<tb>

pulse <SEP> power <SEP> heater. <SEP> This <SEP> is <SEP> more <SEP> than <SEP> 500 <SEP> times

<tb> <SEP> less <SEP> than <SEP> Thermal <SEP> Ink-Jet.
<tb>

Heater <SEP> pulse <SEP> Typically <SEP> approx. <SEP> 40V. <SEP> Approx. <SEP> 5 <SEP> to <SEP> 10V.
<tb>

voltage
<tb> Heater <SEP> peak <SEP> pulse <SEP> Typically <SEP> approx. <SEP> 200 <SEP> mA <SEP> Approx. <SEP> 4 <SEP> mA <SEP> per <SEP> heater.
<tb>

current <SEP> per <SEP> heater. <SEP> This <SEP> requires <SEP> This <SEP> allows <SEP> the <SEP> use <SEP> of <SEP> small
<tb> <SEP> bipolar <SEP> or <SEP> very <SEP> large <SEP> MOS <SEP> MOS <SEP> drive <SEP> transistors.
<tb>

<SEP> drive <SEP> transistors.
<tb>

Fault <SEP> tolerance <SEP> Not <SEP> implemented. <SEP> Not <SEP> Simple <SEP> implementation
<tb> <SEP> practical <SEP> for <SEP> edge <SEP> shooter <SEP> results <SEP> in <SEP> better <SEP> yield <SEP> and
<tb> <SEP> type. <SEP> reliability
<tb> Constraints <SEP> on <SEP> ink <SEP> Many <SEP> constraints <SEP> including <SEP> Temperature <SEP> coefficient <SEP> of
<tb> composition <SEP> kogation, <SEP> nucleation, <SEP> etc. <SEP> surface <SEP> tension <SEP> or <SEP> viscosity
<tb> <SEP> must <SEP> be <SEP> negative.
<tb>

Ink <SEP> pressure <SEP> Atmospheric <SEP> pressure <SEP> or <SEP> Approx. <SEP> 1.1 <SEP> atm
<tb> <SEP> less
<tb> Integrated <SEP> drive <SEP> Bipolar <SEP> circuitry <SEP> usually <SEP> CMOS, <SEP> nMOS, <SEP> or <SEP> bipolar
<tb> circuitry <SEP> required <SEP> due <SEP> to <SEP> high <SEP> drive
<tb> <SEP> current
<tb> Differential <SEP> Significant <SEP> problem <SEP> for <SEP> Monolithic <SEP> construction
<tb> thermal <SEP> expansion <SEP> large <SEP> print <SEP> heads <SEP> reduces <SEP> problem
<tb> Pagewidth <SEP> print <SEP> Major <SEP> problems <SEP> with <SEP> yield, <SEP> High <SEP> yield, <SEP> low <SEP> cost <SEP> and
<tb> heads <SEP> cost, <SEP> precision <SEP> long <SEP> life <SEP> due <SEP> to <SEP> fault
<tb> <SEP> construction, <SEP> head <SEP> life, <SEP> and <SEP> tolerance.<SEP> Self <SEP> cooling <SEP> due
<tb> <SEP> power <SEP> dissipation <SEP> to <SEP> low <SEP> power <SEP> dissipation.
<tb>

Yleld and Fault Tolerance
In most cases, monolithic integrated circuits cannot be repaired if they are not completely functional when manufactured. The percentage of operational devices which are produced from a wafer run is known as the yield.

Yield has a direct influence on manufacturing cost. A device with a yield of 5% is effectively ten times more expensive to manufacture than an identical device with a yield of 50%.

There are three major yield measurements: 1) Fab yield 2) Wafer sort yield 3) Final test yield
For large die, it is typically the wafer sort yield which is the most serious limitation on total yield. Full pagewidth color heads in accordance with this invention are very large in comparison with typical VLSI circuits. Good wafer sort yield is critical to the cost-effective manufacture of such heads.

Figure 5 is a graph of wafer sort yield versus defect density for a monolithic full width color A4 head embodiment of the invention. The head is 215 mm long by 5 mm wide. The non fault tolerant yield 198 is calculated according to
Murphy's method, which is a widely used yield prediction method. With a defect density of one defect per square cm, Murphy's method predicts a yield less than1%. This means that more than 99% of heads fabricated would have to be discarded. This low yield is highly undesirable, as the print head manufacturing cost becomes unacceptably high.

Murphy's method approximates the effect of an uneven distribution of defects. Figure 5 also includes a graph of non fault tolerant yield 197 which explicitly models the clustering of defects by introducing a defect clustering factor.

The defect clustering factor is not a controllable parameter in manufacturing, but is a characteristic of the manufacturing process. The defect clustering factor for manufacturing processes can be expected to be approximately 2, in which case yield projections closely match Murphy's method.

A solution to the problem of low yield is to incorporate fault tolerance by including redundant functional units on the chip which are used to replace faulty functional units.

In memory chips and most Wafer Scale Integration (WSI) devices, the physical location of redundant sub-units on the chip is not important. However, in printing heads the redundant sub-unit may contain one or more printing actuators. These must have a fixed spatial relationship to the page being printed. To be able to print a dot in the same position as a faulty actuator, redundant actuators must not be displaced in the non-scan direction. However, faulty actuators can be replaced with redundant actuators which are displaced in the scan direction. To ensure that the redundant actuator prints the dot in the same position as the faulty actuator, the data timing to the redundant actuator can be altered to compensate for the displacement in the scan direction.

To allow replacement of all nozzles, there must be a complete set of spare nozzles, which results in 100% redundancy. The requirement for 100% redundancy would normally more than double the chip area, dramatically reducing the primary yield before substituting redundant units, and thus eliminating most of the advantages of fault tolerance.

However, with print head embodiments according to this invention, the minimum physical dimensions of the head chip are determined by the width of the page being printed, the fragility of the head chip, and manufacturing constraints on fabrication of ink channels which supply ink to the back surface of the chip. The minimum practical size for a full width, full color head for printing A4 size paper is approximately 215 mm x 5 mm. This size allows the inclusion of 100% redundancy without significantly increasing chip area, when using 1.5gm CMOS fabrication technology. Therefore, a high level of fault tolerance can be included without significantly decreasing primary yield.

When fault tolerance is included in a device, standard yield equations cannot be used. Instead, the mechanisms and degree of fault tolerance must be specifically analyzed and included in the yield equation. Figure 5 shows the fault tolerant sort yield 199 for a full width color A4 head which includes various forms of fault tolerance, the modeling of which has been included in the yield equation.

This graph shows projected yield as a function of both defect density and defect clustering. The yield projection shown in figure 5 indicates that thoroughly implemented fault tolerance can increase wafer sort yield from under1 % to more than 90% under identical manufacturing conditions. This can reduce the manufacturing cost by a factor of 100.

Fault tolerance is highly recommended to improve yield and reliability of print heads containing thousands of printing nozzles, and thereby make pagewidth printing heads practical. However, fault tolerance is not to be taken as an essential part of the present invention.

Fault tolerance in drop-on-demand printing systems is described in the following Australian patent specifications filed on 12 April 1995, the disclosure of which are hereby incorporated by reference:
'Integrated fault tolerance in printing mechanisms' (Filing no.: PN2324);
'Block fault tolerance in integrated printing heads' (Filing no.: PN2325);
'Nozzle duplication for fault tolerance in integrated printing heads' (Filing no.: PN2326);

'Detection of faulty nozzles in printing heads' (Filing no.: PN2327); and
'Fault tolerance in high volume LIFT printing presses' (Filing no.: PN2328).

Pnnting SystemEmbodlments
A schematic diagram of a digital electronic printing system using a print head of this invention is shown in
Figure 6. This shows a monolithic printing head 50 printing an image 60 composed of a multitude of ink
drops onto a recording medium 51. This medium will typically be paper, but can also be overhead
transparencyfiled, cloth, or many other substantially flat surfaces which will accept ink drops. The image to
be printed is provided by an image source 52, which may be any image type which can be converted into a
two dimensional array of pixels.

Typical image sources are image scanners, digitally stored images, images encoded in a page description
language (PDL) such as Adobe Postscript, Adobe Postscript level 2, or Hewlett-Packard PCL 5, page
images generated by a procedure-call based rasterizer, such as Apple QuickDraw, Apple Quickdraw GX, or
Microsoft
GDI, or text in an electronic form such as ASCII. This image data is then converted by an image processing
system 53 into a two dimensional array of pixels suitable for the particular printing system. This may be color
or monochrome, and the data will typically have between 1 and 32 bits per pixel, depending upon the image
source and the specifications of the printing system. The image processing system may be a raster image
processor (RIP) if the source image is a page description, or may be a two dimensional image processing
system if the source image is from a scanner.

If continuous tone images are required, then a halftoning system 54 is necessary. Suitable types of
halftoning are based on dispersed dot ordered dither or error diffusion. Variations of these, commonlyknown
as stochastic screening or frequency modulation screening are suitable. The halftoning system commonly
used for offset printing - clustered dot ordered dither - is not recommended, as effective image resolution is
unnecessarily wasted using this technique. The output of the halftoning system is a binary monochrome or
color image at the resolution of the printing system according to the present invention.

The binary image is processed by a data phasing circuit 55 (which may be incorporated in a Head Control
ASIC 400 as shown in figure 4) which provides the pixel data in the correct sequence to the data shift
registers 56. Data sequencing is required to compensate for the nozzle arrangement and the movement of
the paper. When the data has been loaded into the shift registers 56, it is presented in parallel to the heater
driver circuits 57. At the correct time, the driver circuits 57 will electronically connect the corresponding
heaters 58 with the voltage pulse generated by the pulse shaper circuit 61 and the voltage regulator 62. The
heaters 58 heat the tip of the nozzles 59, affecting the physical characteristics of the ink. Ink drops 60
escape from the nozzles in a pattern which corresponds to the digital impulses which have been applied to
the heater driver circuits.The pressure of the ink in the ink reservoir 64 is regulated by the pressure regulator
63. Selected drops of ink drops 60 are separated from the body of ink by the chosen drop separation means,
and contact the recording medium 51. During printing, the recording·medium 51 is continually moved relative
to the print head 50 by the paper transport system 65. If the print head 50 is the full width of the print region
of the recording medium 51, it is only necessary to move the recording medium 51 in one direction, and the
print head 50 can remain fixed. If a smaller print head 50 is used, it is necessary to implement a raster scan
system. This is typically achieved by scanning the print head 50 along the short dimension of the recording
medium 51, while moving the recording medium 51 along its long dimension.

Digital hlgh speed colorpnnting systems
There are currently two major and widespread methods of printing on paper. For small quantities (typically
less than 100 copies) digital printing using electrophotographic and drop-on-demand printing technologies
are dominant in the home and office. For larger quantities of the same document (typically greater than 1,000
copies) commercial printing using offset and gravure printing presses are dominant.

Typical current home and officepnntzg systems
Figure 6 shows a typical digital office or home printing system in use at the time of writing.The two major
components of the system are a personal computer system 1000 and a desktop printer 1010. The
information to be printed is usually created by one or more application programs. There are many application
programs in common use, which fall into several categories, such as page layout programs, drawing
programs, word processing programs, database programs, spreadsheet programs, CAD programs, image
processing programs, and so on, most of which have differing internal representations (native formats) of the
document to be printed. Most of these programs can use items imported from other applications 1001, and
digital typefaces or fonts 1002. Many application programs 1004 on desktop computers can also import

photographic images. In practice, the use of photographic images is usually limited to low resolution images 1003 with less than approximately one million pixels. This is because high resolution images (of image quality equal to or greater than 35 mm film) typically require 18 MBytes to 100 MBytes of data to store each image. In most circumstances this data must be stored on the disk drive of the personal computer, and in many applications the full image data must reside at least temporarily in the main memory of the computer.

Most desktop computers at the time of writing are not well equipped to efficiently manipulate high resolution photographic images, and so such images are not commonly used in office and home printing. Currently, documents printed in the home and office environments are composed primarily of text, graphics, bitmapped or vector 'clip-art' and low resolution images. Most of the application programs 1004 have the ability to print documents generated in the application.To do this, the internal native format is typically converted to a page description language (PDL) such as Adobe'PostscriptI9', Adobe 'Postscript Level2tom', or Hewlett Packard'PCL5'. Alternatively, the internal representation may be converted to a series of procedure calls to a graphics library, such as Microsoft'GDI ' or Apple Computer'Quickdrawa9' or 'QuickdrawGXTM'. (Product names market withthe ' symbol are trademarks of the corresponding companies preceding the product name.) The document description is provided to the operating system 1005 of the personal computer 1000, which may spool the document to the disk drive 1006.

When the desktop printer 1010 is ready to print a page, the operating system 1005 despools the description of the next page from the disk drive. The page information is then transferred to the desktop printer 1010 via a direct serial or parallel connection, or a local area network. The desktop printer 1010 may contain a PDL interpreter 1012, which converts the page description to a bitmap page representation using digital fonts 1011. The bitmap page representation is stored in a page memory 1013 and printed by the print engine 1014. The page memory 1013 is typically only large enough to store one page image, though in some desktop printers the page memory can store two page images to allow one page to be printed while a subsequent page is being calculated.In most cases, documents are not stored on the printer, so both the personal computer 1000 and the desktop printer 1010 are required to calculate and print any document, even if there has been no change to the document since the last time it was printed.

Typical current commercialDnntmg svstems
Figure 7 shows a typical commercial printing system in use at the time of writing. Three major components are used, typically at three separate sites.

These are the personal computer systems 1000 used for desktop publishing, a prepress service 1030, which converts the electronic page descriptions produced using the personal computer systems 1000 into color separations, and the printer 1040, which makes printing plates using the color separations, and prints the documents typically using an offset press, a color offset press 1041, or, for very high volume printing, a gravure press. Figure 7 specifically shows the systems typically used for color document printing when between 2,000 and 100,000 copies of each document are required. There are many variations in the specific use of equipment, and figure 7 is intended as an approximate guide only.

The information to be printed is usually created by one or more application programs. There are many application programs which may be used to create parts of the final document, such as drawing programs, word processing programs, database programs, spreadsheet programs, CAD programs, image processing programs, and so on. However, the final document is usually composed using a page layout application program 1004, such as Quark'Expressm' or Aldus'Pagemaker'. Page layout programs can use items imported from other applications 1001, digital typefaces or fonts 1002, and color images. Due to the memory, disk space and processing power constraints in desktop computers, high resolution photographic images are typically not used directly in the application programs 1004.Instead, low resolution images are used to mark the position that high resolution images are to take in the final document These low resolution images 1003 may be imported into the application program 1004 using various means, including desktop scanners 1006 used to digitize film transparencies. The document description is normally stored in the native format for the application via the operating system 1005 to a removable storage medium. The removable medium is typically a removable hard disk, an optical disk, or magnetic tape. The document description is usually stored in the native format for the application instead of a page description language to make it easier to make minor changes (such as correcting typographical errors) before the document is printed. The removable media, plus the original transparencies, are then physically taken to the pre-press service company 1030.At the pre-press service company the transparencies are rescanned at high resolution, typically using a drum scanner 1033. The native document description files are converted to Adobe 'Postscript' page description language, and combined with the high resolution scans to produce the final page layout. This page layout

may be printed by a digital proof printer 1034 to obtain customer approval to proceed with the print run. When finalized, the page layout in
Postscript format is sent to a Postscript imagesetter 1032, which produces a set of color separation films. Normally four color separation films are produced, defining the regions where cyan, magenta, yellow, and black ink are to be printed. The color separation films are usually produced at a resolution between 1,800 dpi and 3,600 dpi (inclusive) and usually use clustered dot ordered dithering as the method of halftoning.The high resolution of the color separations is necessary to prevent color banding when using simple clustered dot ordered dithering. Recently, other halftoning techniques such as variations of error diffusion and dispersed dot ordered dithering have been used to decrease the resolution required of the imagesetter, and eliminate such screening problems as rosettes,Moiré, and detail loss in the highlights. Once the color separations are made, a proof sheet is usually made. Once the proof is checked, the color separations are sent to the printer 1040. The printer uses the color separations to make a set of plates for a color offset press 1041. The plates are loaded on the press, and the document is printed.

At present, most high volume full color printing is performed by web fed and sheet fed offset color presses. These machines print color pages using four etched printing plates, one for each of the four color components used in process printing; cyan, magenta, yellow, and black (CMYK). While these machines are highly efficient in printing large volumes of color pages, it is difficult, time consuming, and expensive to change the image being printed. When a new image is to be printed, color separations of the image must be created. Then proof sheets are created, to verify the quality and color of the printed image. These are usually created by a photographic process using the color separations created for the printing press.

When the proof sheets are approved, four printing plates must be etched with the color separation images. Offset presses are also large and expensive and required extensive technical knowledge to operate effectively. Many technical parameters, such as dot gain, registration, and screen angles must be carefully controlled to obtain acceptable results. If the print run is greater than 10,000 copies, the set-up costs of the press can be effectively amortized over the volume printed. However, the cost and time required to set up a color press mean that only rarely is fewer than 1,000 copies of a page printed. If fewer than one hundred copies of a page are to be printed, then digital color copiers are generally used.

Digital color pnnters for commercial and office use
There is increasing recognition in the industry of the need for digital color printing systems which are capable of printing high quality color pages directly from computer data, without requiring photographic and platemaking processes.Desirable characteristics of a full color high speed digital printer for commercial and office use are: 1) > 60 ppm for office printing, > 240 ppm for commercial printing 2) at least 800 dpi print resolution using stochastic screening or error diffusion 3) reduced image noise, for example using CC'MM'YK printing 4) electronic collation and local page storage of at least 1,000 pages 5) automatically prints both sides of the paper (duplex) 6) uses standard PDLs such as Adobe 'Postscript" and Hewlett-Packard 'PCL 5" 7) ability to customize print runs at the full print speed 8) low capital cost for office printing, low price per page for commercial printing 9) high reliability
10) low maintenance
Currently, the cost, size, and maintenance requirements of systems approaching these specifications prohibits their use in the typical office environment.However, a low maintenance digital color printing system using LIFT printing technology, and with specifications similar to those above may achieve considerable commercial success. However, while system cost is not a particularly important consideration for commercial printing, where large offset printing systems can cost as much as $25 million, throughput is important. High throughput, flexible operation, incremental investment, and high system reliability and uptime can be achieved by using multiple machines of moderate throughput. While parallel operation of multiple machines can increase throughput to any desired level, capital costs also scale with the number of machines used. For this reason, it is desirable that the capital cost of a single digital printer is relatively low compared to that of offset printers.To achieve widespread use in the commercial market, the price of a single printer unit as disclosed herein is preferably less than US $100,000. Cost, on the other hand, is very important in the office market. To achieve widespread use in the office market, the cost of the printer system is preferably less thanUS$20,000, with a price of approximately US$10,000 being a highly desirable target
One of the significant problems in achieving cost targets such as these is the cost of electronic collation. Electronic collation requires the digital storage images of all of the pages in the document. The page images can be stored in a variety of formats, such as full bitmaps, compressed bitmaps, or in a page description language (PDL). Storage of the pages in PDL format has the significant disadvantage that each page must be rasterized each time it is printed.For many pages (especially those containing images or complex graphics) rasterization takes much longer than the one second or so required to print the page. Therefore, storing page images in PDL format for electronic collation will typically make the printer operate at much less

than full speed. Storing the page images as uncompressed bitmaps creates problems with storage capacities and data rates. For example, an A4 page at 800 dpi with six bits per pixel (using the CC'MM'YK color model) requires approximately 46 MBytes per page. To print one duplex page per second requires a data rate of approximately 92 MBytes per second. Electronic storage of 1,000 pages requires 46 GBytes of data storage.While both the storage requirements and the data rate are technically achievable, the cost of such equipment using currently available semiconductor memories and disk drives is well in excess of the targeted US $10,000 retail price of the entire printer system.

Electronic collation using compressed, pre rasterized bitmaps can provide a solution to this problem. Desirable characteristics of such a system for commercial printing use are: 1) 10,000 or more pages stored in a high reliability RAID 10 GByte disk array 2) Fast compression (comparable to, or less than, the raster image processing time) 3) Sustained data rate required from disk of less than 4 MBytes per second to allow the use of low cost disk drive arrays 4) Real-time expansion of the compressed page images 5) Expansion can operate approximately synchronously to the print engine, so that a full page memory is not required 6) Negligible image quality loss
Desirable characteristics of an office system are: 1) More than 1,000 pages stored in a low cost 1 GByte disk drive 2) Fast compression (comparable to, or less than, the raster image processing time) 3) Compression can operate on a band-by-band basis, so that a full page memory is not required 4) Sustained data rate required from disk of less than 1 MByte per second to allow the use of a single low cost disk drive 5) Real-time expansion of the compressed page images 6) Expansion can operate approximately synchronously to the print engine, so that a full page memory is not required 7) Negligible image quality loss.

To achieve these specifications, a compression rate of approximately 80: 1 must be achieved with negligible image quality loss.

Figures 8(a) and 8(b) are schematic block diagrams of commercial and office digital printing systems. Figure 8(b) shows workflow from the source images and text compiled using a desktop publishing system, through to the print engines used to print the material. The three major systems involved are the personal computer system 1000 of the publisher, pre-press equipment 1030 of a pre-press service provider (who may also be the printing service provider) and one or more high speed digital color printers 1050. In Figure 8(a), the digital office color printer uses a personal computer system 1000. The document to be printed is created using application programs 1004, which may incorporate fonts 1002, digital images 1007 from various sources, items imported from other applications 1001, and low resolution images 1003 from a desktop scanner 1006.Application programs are becoming available which can manipulate low resolution images, and then automatically apply the same manipulations to a high resolution version of the same image. The low resolution images are often called proxy images. This type of application is well suited to producing high quality color documents within the limitations of currently available personal computer systems. When the document is to be printed, the page description containing proxy images is combined with the high resolution images in a process of proxy image replacement 1008. The document description may be in the form of a Page Description Language (PDL), which may be saved by the operating system 1005 onto a disk drive 1009.

Referring to Figure 8(b), the document description may be stored in the native format for the application via the operating system 1005 to a removable storage medium 1050. The removable medium may be a removable hard disk, an optical disk, or magnetic tape. High speed network connections directly from the publisher to the pre-press service may be available in some cases. The document description is usually stored in the native format for the application instead of a page description language to make it easier to make minor changes (such as correcting typographical errors) before the document is printed. The removable media, plus the original transparencies if higher quality scans are required, are then physically taken to the pre-press service 1030. At the pre-press service the transparencies may be re-scanned at high resolution, typically using a drum scanner 1033.The native document description files are converted to Adobe 'Postscript' page description language, and combined with the high resolution scans to produce thefinial page layout. The completed document including high resolution images may be transferred to the printer via a high speed local area network (LAN).

Still with respect to Figure 8(b), high speed color digital printers 1050 may be connected to the high speed LAN. The number of printers used for any particular print job can be varied depending upon the number of pages to be printed. Print jobs with less than 10,000 total pages are preferably sent to a single printer, as the print job can be completed in a little over one hour. Printjobs with more than 100,000 pages (such as color magazines or catalogues) are preferably distributed over a number of printers. A print job of 100,000 pages distributed over 4 printers could be complete within 3 hours.

Referring now to Figure 8(a), as printer 1050 becomes ready to accept each page representation, it is despooled from the disk drive 1009, and transferred to the printer in a network or direct connection.

A PDL interpreter 1051 in the printer 1050 rasterizes the page descriptions using fonts 1052. If the PDL has a band rendering capability, then a band memory 1053 can be used instead of a page memory. The use of a band memory has a significant advantage in saving cost, as a full page memory for A4 CC'MM'YK printing at 800 dpi requires 46 MBytes of page memory. For rendering efficiency this would need to be implemented in semiconductor memory.

The use of a band rendering PDL, such as some versions of Postscript', or Canon 'OpenPage", can reduce the memory requirement significantly. A 48 line band of an A4 CC'MM'YK page at 800 dpi requires only 240 KBytes of memory. This is a reduction of nearly 200 times the amount of memory required. This amount of semiconductor memory is presently expensive relative to the target price of the office printer of Figure 8(a).

It is not necessary for the band rendering operation to proceed in real time, as compressed page images which can be expanded in real time are generated. Therefore, it is practical to use software implementations of the PDLinterpreter/RIP process without requiring specific hardware acceleration. However, it is preferable in the commercial system of Figure 8(b) that a high speed processor be used to RIP the pages, to prevent RIP speed becoming a major 'bottleneck' for small print runs.

After each band is rendered by the PDL interpreter, it is compressed by the compression system 1054 and saved to the redundant array of inexpensive disks (RAID) of Figure 8(b) or the disk drive of Figure 8(a). After all of the bands in the page have been rendered, the RAID or disk drive contains a complete compressed page image. The page may be printed at this time, but it will often be preferable to rasterize and compress the entire document before printing any pages.

This allows full electronic collation, and also ensures that the compressed page image for the reverse side of the page is also ready when printing the front of the page.

When a page is to be printed the compressed page image is read from the disk drive 1055 and expanded in real time by the expansion system 1056.

Expanded page image data is stored in a band memory 1057 and printed on the print engine 1058.

Uses of electronic collation and storage
There are two major uses of a high capacity digital page storage facility in a commercial or office printing system. These are electronic collation, and document printing on demand without involving the computer which created the document.

Electronic collation is the printing of pages in an order which is convenient for the user, rather than simple for the computer and printing system.

When using electronic collation, each entire document is printed in the correct page order, eliminating the requirement for manual collation. The use of electronic collation can eliminate the requirement for large mechanical collation machines, and the large amount of paper storage space required for uncollated sheets.

Print on demand for rarely changing documents is another significant application of a high capacity digital page storage system located in a printer. With print on demand facilities, a customer can order as many copies of a document (for example, a brochure or catalogue) as are required on a daily or weekly basis. The copies can then printed without incurring any setup costs, RIP time, or storage costs. There are major advantages of this system over storing pre-printed documents, including:1) The elimination of waste resulting from disposal of out of date documents 2) Only those documents which are required are printed 3) A reduction in storage space required 4) Documents can be kept much more up-to-date, and can be changed simply and frequently.

Documents which may typically be stored on the disk drive of
Figure 8(a) and printed on demand include those shown in the table "Potential use of page storage":
Potential use of page storage
EMI50.1

<tb> Number <SEP> of <SEP> Description <SEP> Pages <SEP> Total
<tb> documents <SEP> each
<tb> <SEP> 50 <SEP> Product <SEP> brochures <SEP> 8 <SEP> 200
<tb> <SEP> 5 <SEP> Company <SEP> and <SEP> division <SEP> brochures <SEP> 16 <SEP> 80
<tb> <SEP> 1 <SEP> Corporate <SEP> newsletter <SEP> 16 <SEP> 16
<tb> <SEP> 2 <SEP> Product <SEP> catalogues <SEP> 50 <SEP> 100
<tb> <SEP> 1 <SEP> Annual <SEP> report <SEP> 50 <SEP> 50
<tb> <SEP> I <SEP> In-house <SEP> magazine <SEP> 64 <SEP> 64
<tb> <SEP> 50 <SEP> Various <SEP> paper <SEP> forms <SEP> 1 <SEP> 50
<tb> <SEP> 50 <SEP> Miscellaneous <SEP> staff <SEP> notices <SEP> and <SEP> posters <SEP> 1 <SEP> 50
<tb> <SEP> 1 <SEP> Collation <SEP> buffer <SEP> for <SEP> current <SEP> document <SEP> 200 <SEP> 200
<tb> <SEP> Total <SEP> ~ <SEP> <SEP> 810
<tb>
However, easy and instant access to color documents in office situations, combined with a significant cost reduction resulting from the ability to print single copies on demand, is likely to cause a significant proliferation in the types and quantity of color documents published by companies. Because the printing system is fast, longer documents such as user manuals and service manuals for the company's products may also be stored on the disk drive in the printer and printed on demand. It is easy to imagine the requirement for tens of thousands of pages to be stored on the printer. Fortunately, this is easy to achieve by adding disk drive capacity.It is also cost effective, as approximately 1,000 A4 color pages can be stored per GByte of disk storage
Documents which may typically be stored on the disk drive of
Figure 8(b) and printed on demand include those shown in the table "Potential use of page storage for commercial printing":
Potential use of page storage for commercial printing
EMI51.1

<tb> Number <SEP> of <SEP> Description <SEP> Pages <SEP> Total
<tb> documents <SEP> each
<tb> <SEP> 400 <SEP> Average <SEP> of <SEP> 8 <SEP> brochures <SEP> for <SEP> each <SEP> of <SEP> 50 <SEP> customers <SEP> 8 <SEP> 3,200
<tb> <SEP> 50 <SEP> Average <SEP> of <SEP> 1 <SEP> letterhead <SEP> for <SEP> each <SEP> of <SEP> 50 <SEP> customers <SEP> 1 <SEP> 50
<tb> <SEP> 40 <SEP> Average <SEP> of <SEP> 2 <SEP> product <SEP> catalogues <SEP> for <SEP> each <SEP> of <SEP> 20 <SEP> 50 <SEP> 2,000
<tb> <SEP> customers
<tb> <SEP> 50 <SEP> 1 <SEP> Annual <SEP> report <SEP> for <SEP> each <SEP> of <SEP> 50 <SEP> customers <SEP> 50 <SEP> 2,500
<tb> <SEP> 250 <SEP> Average <SEP> of <SEP> 5 <SEP> forms <SEP> for <SEP> each <SEP> of <SEP> 50 <SEP> customers <SEP> 1 <SEP> 250
<tb> <SEP> 500 <SEP> Average <SEP> of <SEP> 10 <SEP> miscellaneous <SEP> documents <SEP> for <SEP> 1 <SEP> 500
<tb> <SEP> each <SEP> of <SEP> 50 <SEP> customers
<tb> <SEP> 1 <SEP> Collation <SEP> buffer <SEP> for <SEP> current <SEP> document <SEP> 1,000 <SEP> 1,000
<tb> <SEP> Total <SEP> = <SEP> <SEP> 9,500
<tb>
While the commercial system of Figure 8(b) provides a page storage capacity of approximately 10,000 pages, this number is determined primarily by the disk drive capacity. It is simple to vary the disk capacity significantly, to obtain much greater page storage capacities.Lower cost systems with lower page storage capacities can also be readily achieved. Approximately 1,000 A4 color pages can be stored per GByte of disk storage. This means that the current retail cost of storage is approximately US $0.50 per page. This cost is decreasing rapidly as the cost of disk drive capacity continues to fall.

Compression svstem for electronic collation and page storage
The compression scheme described herein is aspeciiic example of page compression, based on certain

constants. These constants can easily be parameterized to generalize the compression to be applicable to a wide range of circumstances. The specific constants assumed herein are: 1) Page size is 210 mm x 293 mm (A4). This can be parameterized to accommodate different page sizes.

2) Print area: same as page size. This allows full bleed printing, but with no tolerance for paper misalignment. The print area can be parameterized to accommodate non-printing margins, and/or alignment error for full bleed printing.

3) The resolution is 800 dpi in both axes. This can be parameterized to match the printing resolution of the printer. The resolution in the scan direction need not be the same as the resolution in the non-scan direction.

4) The color space used is CMYK. The use of other color spaces such as RGB or device independent color spaces can be accommodated with obvious modifications to the compression scheme.

5) The contone color resolution supported is 266.6 dpi (800 dpi divided by three).

This is the maximum color resolution supported by offset printing using a 133 line screen, and is generally considered to be 'magazine quality'. Greater or less color resolution can be supported, though it is convenient if the printer resolution is an integral multiple (in this case, 3) of the contone resolution.

The compression scheme is described in relation to these specific parameters to simplify description and to allow easy comparison with 800 dpi A4 color printing which does not use compression.

Figure 9 shows a data representation of the compression scheme.

The A4 page 1100 is divided into a rectangular matrix of 276 cells by 390 cells 1101. Each cell 1101 is an array of 24 x 24 pixels (576 pixels) at the printer resolution (800 dpi). The size of each cell when printing at 800 dpi is 0.76 mm (0.03"). When fully expanded to a halftoned image, each cell 1101 requires 288 bytes if halftoned to CMYK, or 432 bytes if halftoned to CC'MM'YK.

Each cell 1101 has a two bit cell type field 1102 associated with it.

The two bits of a cell type field 1102 define four states of a cell 1101: 1) White: all pixels in the cell 1101 are white. No further information is required.

All white cells will occur frequently in borders, whitespace, space between lines, etc. Whitespace is compressed by 1728:1 when using the CC'MM'YK color model.

2) Black on white: all pixels in the cell 1101 are either black or white. The pattern of black and white pixels is defined by further information. This occurs frequently in text.

3) One color on white: all pixels in the cell 1101 are either white or a single other color. The color and pattern of colored pixels is defined by further information.

This occurs mainly in colored text, charts, and outline graphics.

4) Contone color: all other conditions of the cell 1101 are considered to be continuous tone (contone) color. Contone color cells are subsampled and JPEG (Joint Photographic Experts Group) compressed. To prevent degradation of the edges of black text over contone images, black pixels are extracted before subsampling and JPEG compression, and are processed in a similar way to black on white cells. When the page image is expanded, the expanded black image is superimposed on the expanded JPEG contone image. The contone images are
JPEG compressed at a compression ratio of approximately 20:1. When 266 dpi contone images are expanded after JPEG compression at a 20:1 compression ratio, image degradation is usually not noticeable.

The cell type field 1102 can be a rectangular array of two bit values, which may be packed into bytes or words. A simple array data structure simplifies the design of hardware which may be required in some applications to achieve realtime expansion of the compressed page images.

Cells 1101 in which the cell type field 1102 is 'black and white' are divided into a 3 x 3 array of 8 pixel x 8 pixel subcells 1103. Each subcell 1103 has a two bit subcell type field 1105. The two bits of a subcell type

field 1105 define four states of a subcell 1103: 1) White: all pixels in the subcell 1103 are white. No further information is required. All white cells will occur frequently in borders, whitespace, space between lines, etc. The lossless compression ratio for this data type is 173:1 for the CC'MM'YK color model.

2) Black or solid color: all pixels in the subcell 1103 are black. No further information is required. This occurs frequently inside the strokes of text characters.

The width of the strokes of even body text (typically 10 point) is usually large enough to contain subcells which are all black. The lossless compression ratio for this data type is 173:1 for the CC'MM'YK color model.

3) Pattern: this occurs if the pattern of black pixels in a subcell is one of the common patterns shown in figure 10. The pattern is identified by an 8 bit pattern
ID 1106, allowing up to 256 common patterns. The lossless compression ratio for this data type is 37.5:1 for the CC'MM'YK color model.

4) Explicit pattern: this is the degenerate case which occurs if the pixel pattern is not one of the common cases. The pattern of selected drops in the subcell is directly specified by an 8 x 8 bitmap 1107, requiring 64 bits. The lossless compression ratio for this data type is 5.8:1 for the CC'MM'YK color model.

Cells 1101 in which the cell type field 1102 is 'one color on white' have a color specification 1104 of the one color (the selected color) associated with them. The color specification 1104 is preferably in the same color space as the remainder of the image, as may be expressed using 8 bits per color component, for a total of 32 bits if the color space is CMYK, or 24 bits if the color space is RGB.

The cells are also divided into a 3 x 3 array of 8 pixel x 8 pixel subcells 1103. Each subcell 1103 has a two bit subcell type field 1105. The two bits of a subcell type field 1105 define four states of a subcell 1103: 1) White: all pixels in the subcell 1103 are white. No further information is required. These subcells will principally occur around and within colored text. The lossless compression ratio for this data type is 66.5:1 for the CC'MM'YK color model.

2) Black or solid color: all pixels in the subcell 1103 are the selected color. No further information is required. This occurs frequently inside the strokes of colored text characters. The lossless compression ratio for this data type is 66.5:1 for the CC'MM'YK color model.

3) Pattern: this occurs if the pattern of selected color in a subcell is one of the common patterns shown in figure 10. The pattern is identified by an 8 bit pattern
ID 1106, allowing up to 256 common patterns. The lossless compression ratio for this data type is 27.9:1 for the CC'MM'YK color model.

4) Explicit pattern: this is the degenerate case which occurs if the pixel pattern is not one of the common cases. The pattern of selected drops in the subcell is directly specified by an 8 x 8 bitmap 1107, requiring 64 bits. The lossless compression ratio for this data type is 5.5:1 for the CC'MM'YK color model.

Cells 1101 in which the cell type field 1102 is 'contone color' are further divided into two categories: those cells 1101 which contain black and those cells 1101 which do not contain black. The black component is compressed losslessly, and the color component is reduced to a lower resolution and JPEG compressed. The reason for this is to preserve the readability of black text on colored or photographic backgrounds. Only black text is treated in this manner, as the use of colored text on colored background is rarely used, and when it is used, the text is usually in large point sizes. This aspect of the compression scheme matches expectations which derive from viewing color offset printed material, which reproduces black text on colored backgrounds well.Small point size colored text is typically not used in offset printing because it will usually be screened, and become difficult to read due to screening artifacts.

All pixels in the cell 1101which are black are marked in a 24 x 24 bitmap. This bitmap is then compressed in the same manner as cells 1101 where the cell type field is 'black on white'. The black pixels in the cell 1101 are then replaced with a color which is representative of the color which that pixel would be if it were not covered with black text. The method ofdeter nining this color is not especially important. For example, it may be the average color of all non-black pixels in the cell, or it may be the color of the nearest non-black pixel found when following a search pattern, or it may be the average of the colors of neighboring non-black

pixels, weighted by the inverse of the distance between the black pixel and the particular non-black pixel.The reason for replacing black pixels with a color which is closer to non-black colors in the cell is to reduce 'mosquito noise' that occurs when JPEG compressing high frequency patterns with a highluminance or chrominance difference. This mosquito noise affects the colors of other pixels in the cell. The exact choice of color is not important, as it is replaced with black when the cell is expanded. After black pixels have been replaced, the cell 1101 is reduced to a resolution of 266.6 dpi. This can be achieved decimating the cell by a factor of 3 (selecting every third pixel in every third row). However, a simple decimation can lead to aliasing artifacts. It is preferable to make the color of each pixel of the 8 x 8
PEG cell 1109 equal to the average color of each corresponding 3 x 3 square of pixels in the 24 x 24 pixel cell 1101.For slightly higher image quality, the cell 1101 can be low-pass filtered before decimation. However, the very small improvement in image quality afforded by low pass filtering over simple averaging is unlikely to warrant the significant additional computational expense. JPEG (Joint Photographic Experts Group) encoding of the JPEG cell 1109 is chosen over other contone image compression methods such as fractal or wavelet compression due to its good image quality at moderate compression ratios, international standardization, symmetry in encoding and decoding, well defined operation on separate square blocks, and availability of high speed JPEG compression and expansion chips, which are useful in ensuring that expansion of page images can occur in real-time for high speed printing systems.JPEG compression of 20:1 at 266.6 dpi results in a lossy compression ratio of 42:1 over a CC'MM'YK bitmap, and a compression ratio of 225:1 over a contone image at 800 dpi. This is achieved with an image degradation which is usually not visible to the naked eye as the image quality benefits considerably from the removal of black text before compression.

Figures 10(a) and 10(b) show a set of common patterns that may be encoded by the pattern ID 1106. An 8 x 8 pattern of bi-level pixels has 264 = 1.84 x 10'9 possible states. The use of pure frequency encoding is impractical, as the table would need to contain all of these states. In this scheme, pure black or white patterns encode to two bits, a set of up to 256 common patterns encodes to 10 bits, and all other patterns encode to 66 bits. In preference to the using the theoretical maximum compression which can be obtained using frequency encoding, an easily implemented system where the encoding can be defined by simple algorithms without requiring time consuming table comparisons and large tables is chosen.

At 800 dpi, each 8 x 8 pattern of pixels represents an area of only a quarter of a millimeter squared (0.01" x 0.01"). Each character of text in 10 point
Times font at normal line spacing covers an average area equal to approximately 100 of these patterns.

Pattern 1200 is white, and is encoded in two bits as the white state of the subcell field type. Pattern 1201 occurs when each pixel is the selected color or black.

Patterns 1202 and 1203 are two patterns which may occur when a 50% density is represented. Some programs produce this representation instead of specifying a 50% tone. Patterns 1204 to 1259 are all of the patterns produced by a vertical stripe of any width in either the selected color or white. The main occurrence of these patterns is on the vertical edges of text characters. Patterns 1260 to 1315 are all of the patterns produced by a horizontal stripe of any width in either the selected color or white. The main occurrence of these patterns is on the horizontal edges of text characters. Patterns 1316 to 1371 are patterns resulting from a diagonal division between the selected color and white. Patterns 1372 to 1451 are patterns resulting from a division between the selected color and white which occurs at a slope of 2.High compression ratios for text can be achieved by allowing small variations from the patterns shown in figure 10 to be encoded to those patterns. This reduces the incidence of the 'Explicit Pattern' subcell type, which has a low compression ratio. Variations of a few pixels on the black to white edges of the patterns will normally not be detected with the naked eye when printed at 800 dpi.

There are fourteen different combinations of cell types 1102, subcell types 1105 and text overlay flags 1108 which result in different 'encoding types'.

'Typical' compression ratios
The table "Compression ratio for a 'typical' page by encoding type" shows compression ratios for the different encoding types supported by this compression scheme. Also shown is the average portion of a page which may be expected to be compressed to each encoding type. The average portion of a page for each encoding type will vary based upon the type of documents that are printed.

The portions shown in the 'Average portion of page' column of the table are derived from measurements of a number of full color monthly magazines, where each page is printed using a four color process. In these

magazines, there is no additional cost in the inclusion of more color area on a page. It is assumed that when there is no penalty (in either printing cost or time) for printing in color that the amount of color used in office publications will eventually approach the use of color in full color magazines.

Compression ratio for a 'typical' page by encoding type
EMI58.1

<tb> Cell <SEP> Type <SEP> Subcell <SEP> Averag <SEP> Bytes <SEP> Compression <SEP> Compression
<tb> <SEP> Type <SEP> e <SEP> per <SEP> ratio <SEP> versus <SEP> ratio <SEP> versus
<tb> <SEP> portion <SEP> page <SEP> CC'MM'YK <SEP> CMYK
<tb> <SEP> of <SEP> page <SEP> bitmap <SEP> ~ <SEP> <SEP> contone
<tb> White <SEP> - <SEP> 40% <SEP> 10,764 <SEP> 1,728 <SEP> 9,216
<tb> Black <SEP> on <SEP> white <SEP> White <SEP> 18% <SEP> 48,438 <SEP> 172.8 <SEP> 921.6
<tb> Black <SEP> on <SEP> white <SEP> Black <SEP> 9% <SEP> 24,219 <SEP> 172.8 <SEP> 921.6
<tb> Black <SEP> on <SEP> white <SEP> Pattern <SEP> 2.4% <SEP> 29,709 <SEP> ~ <SEP> <SEP> 37.6 <SEP> 200.3
<tb> Black <SEP> on <SEP> white <SEP> Explicit <SEP> 0.6% <SEP> 48,115 <SEP> 5.8 <SEP> i <SEP> 30.9
<tb> Color on white White 1.2% 8,396 66.5 354.5
Color on white Black 0.6% 4,198 66.5 354.5
Color on white Pattern 0.16% 2,669 27.9 148.6
Color on white Explicit 0.04% 3,380 5.5 29.4
Contone - 25% 275,82 42.1 224.8
8
Contone & Text White 1.8% 24,219 34.6 184.3
Contone & Text Black 0.9% 12,110 34.6 1 184.3
Contone & Text Pattern 0.24 o 5,554 20.1 107.2
Contone & Text Explicit 0.06% 5,457 5.1 27.3
Total <tb> <SEP> 6
<tb>

The average compression ratio for a 'typical' page is 92.4:1 compared to a CC'MM'YK full bleed 800 dpi bitmap, and 493:1 compared to a
CMYK full bleed 800 dpi contone image. This allows the typical page to be stored in approximately 500 KBytes, allowing storage of well over 1,000 pages on a low cost 1 GByte disk drive. The sustained data rate required from disk is approximately 1 MByte/second for a print speed of 120 ppm (one two sided A4 page per second). This can be achieved using low cost SCSI disk drives. The maximum commonly encountered data rate will be for full page contone images.

These will compress to approximately 1.1 MBytes each. To maintain 120 ppm print speed when full bleed color pages are encountered, the disk drive would preferably be able to sustain a data rate in excess of 2.2 MBytes per second. This is especially relevant for web fed printers. For sheet fed printers, a pause of one second or so when full color pages are encountered will often be acceptable.

Compressionencoding algonthm
It is preferable that the image to be compressed is in the form of a 32 bit per pixel CMYK contone image. Other forms are possible, such as an RGB contone image, images in different color spaces, and images with different color resolution. It is also preferable that the page to be printed be created in bands that are 24 lines wide so that an entire contone page memory is not required. An A4 full bleed 800 dpi 32 bit per pixel contone page memory would require 247 MBytes of memory. A 24 line band of such an image requires 635 KBytes of memory. If the compression process can proceed simultaneously (or as a separate thread) then it is preferable to double-buffer the bands, so that two band buffers are required, for a total of 1.27 MBytes.

The following is an algorithm in pseudocode for encoding to the compression scheme disclosed herein:
Define Band~width = 276
Define Page~length = 390
Define Cell = 24 x 24 array of 32 bit CMYK colors
DefineBitmap,cell = 24 x 24 array of Booleans
Define JPEG~Cell = 8 x 8 array of CMYK colors
Define Other~color = 32 bit CMYK color specification

Define White~cell = 2 bit binary 00
Define Black~and~white~cell = 2 bit binary 01
Define Color~and~white~cell = 2 bit binary 10
Define Contone~cell = 2 bit binary 11
Define False = 1 bit binary 0
Define True = 1 bit binary 1
Clear Compressed~data
Clear JPEG~compressed~data
Append Band~width to Compressed~data
Append Page~length to Compressed~data
For Band =0 toPage,length - 1
Calculate Band (The calculation of the Band is performed by the prior art PDL interpreter or other raster image processor system)
For Cell~in~band = 0 to Band~width - 1
Set Other~color = color of first non white pixel in cell
Case
All pixels in Cell are white
Append White~cell to Compressed~data
All pixels in Cell are either white or black
Append Black~and~white~cell to Compressed~data
For (x,y) = (0,0) to (23,23)
If Cell(x,y) = black
Set Bitmap~cell(x,y) = true
Else
Set Bitmap~cell(x,y) = false
Endif
Next (x,y)
Call subroutine Bitmap~encode[Bitmap~cell, Compressed data)
All pixels in Cell are either white or Other~color
Append Color~and~white~cell to Compressedata
Append Other~color to Compressed~data
For (x,y) = (0,0) to (23,23)
If Cell(x,y) = Other~color
Set Else
SetConfiguration <SEP> Desktop
<tb> Printer <SEP> type <SEP> 2 <SEP> drop <SEP> selection <SEP> and <SEP> separation <SEP> full <SEP> width <SEP> printing
<tb> <SEP> heads <SEP> for <SEP> duplex
<tb> Number <SEP> of <SEP> nozzles <SEP> 79,488 <SEP> active <SEP> nozzles, <SEP> 79,488 <SEP> spare <SEP> nozzles
<tb> Paper <SEP> size <SEP> A4, <SEP> US <SEP> letter
<tb> Printing <SEP> speed <SEP> 74 <SEP> ppm <SEP> duplex <SEP> (37 <SEP> sheets <SEP> per <SEP> minute)
<tb>
EMI74.1

<tb> Local <SEP> document <SEP> storage <SEP> 1,000+ <SEP> pages
<tb> Electronic <SEP> collation <SEP> up <SEP> to <SEP> 1,000 <SEP> page <SEP> documents
<tb> Disk <SEP> capacity <SEP> 1 <SEP> GByte
<tb> Printer <SEP> resolution <SEP> 800 <SEP> dpi
<tb> Paper <SEP> volume <SEP> 3,000 <SEP> sheet <SEP> motorized <SEP> feeder
<tb> Weight <SEP> Approx.<SEP> 20 <SEP> kg
<tb> Dimensions <SEP> (W <SEP> X <SEP> D <SEP> X <SEP> H) <SEP> 800 <SEP> X <SEP> 250 <SEP> X <SEP> 350 <SEP> mm
<tb> Page <SEP> description <SEP> language <SEP> Adobe <SEP> Postscript* <SEP> level <SEP> 2, <SEP> PCL5*
<tb> Connectivity <SEP> Ethernet, <SEP> LocalTalk*, <SEP> Centronics <SEP> *, <SEP> SCSI
<tb>
* 'Postscript' is a registered trademark of Adobe Systems
Incorporated, 'PCL5' is a trademark of Hewlett-Packard Corporation, 'LocalTalk' is a trademark of Apple

Computer Inc., 'Centronics' is a trademark of Centronics
Inc.

The table "LIFT head type A4-6-800" is a summary of some characteristics of an example full color
monolithic drop selection and separation printing head suitable for use in the color printer disclosed herein.

This printer system has many advantages over prior-art systems.

Some of these advantages are high speed, high image quality, local page storage, electronic collation, low
cost, and relatively small size.

High speed on-demand pnnterusing drop selection and separationDnntmg
The table "Example product specifications" shows the specifications of one possible configuration of a high
speed on-demand printer using drop selection and separation printing technology and a digital page image
store for electronic collation and local digital document storage.

Example product specifications
EMI75.1

<tb> Configuration <SEP> Floor <SEP> standing, <SEP> web <SEP> fed
<tb> Web <SEP> width <SEP> 420 <SEP> mm
<tb> Printer <SEP> type <SEP> 4 <SEP> x <SEP> LIFT <SEP> A4 <SEP> page <SEP> width <SEP>
printing <SEP> heads
<tb> Number <SEP> of <SEP> nozzles <SEP> 158,976 <SEP> active <SEP> nozzles, <SEP> 158,976
<SEP> spare <SEP> nozzles
<tb> Printing <SEP> speed <SEP> 128 <SEP> A4 <SEP> ppm <SEP> duplex <SEP> (37 <SEP> A3
<SEP> sheets <SEP> per <SEP> minute)
<tb> Local <SEP> document <SEP> storage <SEP> 10,000+ <SEP> pages
<tb> Electronic <SEP> collation <SEP> up <SEP> to <SEP> 10,000 <SEP> page <SEP> documents
<tb> Disk <SEP> capacity <SEP> 10 <SEP> GBytes
<tb> Printer <SEP> resolution <SEP> 800 <SEP> dpi
<tb> Dimensions <SEP> (WX <SEP> DX <SEP> H) <SEP> 1,500 <SEP> X <SEP> 700 <SEP> X <SEP>
1,800 <SEP> mm
<tb> Page <SEP> description <SEP> language <SEP> Adobe <SEP> Postscript* <SEP> level <SEP> 2
<tb> Connectivity <SEP> 100 <SEP> BaseT <SEP> Ethernet
<tb> Physical configuratlon
There are many possible physical configurations of the invention.

Because the printing speed is high, and the high speed office printer system is intended to be used to print
multiple copies of multiple page documents without human intervention, it is desirable to provide a relatively
large paper supply.

A paper supply of at least 6 reams (3,000 sheets) of paper is desirable. At full printing speed, this paper
supply would last less than one hour. Motorized sheet feeders with a capacity of 3,000 or more sheets of
paper are well known in the industry, and are commonly used for photocopiers with a copy speed of more
than 20 cpm. The print head, ink supply system, and printer electronics can be manufactured with a total
volume less than the volume of 3,000 A4 sheets, so the size and configuration of a desktop printer using this
system is likely to be dominated by paper storage and handling mechanisms.

Figure 12 shows a perspective view of the layout of major components for one possible configuration of such
a printer. The printer includes: ink reservoirs 920; an enclosure 930 containing power supplies, power
electronics, and a hard disk drive; a circuit board 900 containing the control electronics and electronic
collation system; two page-width print heads 50; ink channels 75; platens 67; a paper pick-up roller 912;
paper transport rollers 65; a control panel 901; a motorized paper input tray 910; and a motorized paper
output tray 911. Figure 12 is intended to be representative only, and does not show all of the required
components of the system.Items not shown include: connections to a computer or power source; electrical
wiring between subsystems of the printer; ink pressurizing systems; ink transport systems; ink heating
systems if hot melt ink is used; paper guides; drive motors gears, belts, or chains for the paper transport
mechanisms; covers for the printer, and so forth. These are well known in the art, and depend upon the
configuration of the printer.

In this example printer configuration, there are six ink reservoirs 920. These are for the colors213 density cyan, 1/3 density cyan, 2/3 density magenta, 1/3 density magenta, yellow and black that are used in the CC'MM'YK color model. If other color models are used, a different number of ink reservoirs 920 may be required.

When printing, the motorized paper input tray 910 keeps the top of the stack of blank paper level with the paper pick-up roller 912. This can be achieved using well known optical or mechanical sensors, which control a motor which raises or lowers the paper input tray. Sheets of paper 51 are grabbed by the paper pick-up roller 912 and passed to the paper transport rollers 65. One side of the page is printed by a first page-width drop selection and separation print head 50, and the other side of the page is printed by a second page-width drop selection and separation print head 50. Data for the print heads 50 is provides by real-time expansion circuitry located on the circuit board 900. When printed, the paper is ejected into the output paper tray 911, which also has a capacity of 3,000 sheets.

The output tray may be motorized to keep the top of the stack of output paper just below the level of the paper transport rollers 65. This is so that printed sheets do not have room to tumble over as they fall onto the stack of output paper.

Alternative designs which prevent the paper from tumbling over or otherwise misstacking without using a motorized system may be used. A motorized output tray is also not necessary if the output capacity required is less than approximately 500 pages. However, the printer cannot operate unattended for longer print runs than the output capacity, so provision of an output capacity commensurate with the input paper capacity is desirable.

The paper path shown in figure 12 is very short and straight. This has several advantages: 1) the printer can be made more compact; 2) paper curl is reduced; and 3) the potential for paper jams is considerably reduced.

However, a short paper path as shown in figure 12 is preferably only used with very fast drying inks, or with hot melt inks. If the ink drying time is longer than one second, there is a possibility of ink on newly printed sheets bleeding through to previously printed sheets in the output paper tray 911. At present, hot melt inks provide the best option for very fast drying. The paper transport rollers 65 can be used to cold press the hot melt ink. If hot melt ink bonding to the paper is insufficient, the platens 67 can be heated to increase wicking of the hot melt ink into the paper before the ink freezes. Heating the paper during printing will generally also increase the spot size, which may or may not be desirable, depending upon the particular characteristics of the ink, print head, and paper.

The control panel 901 can include devices such as buttons and a display. While operation as a network printer can be remotely controlled from the computer from which the print job originates, a control panel is desirable for local operations. The control panel preferably provides the ability to locally select a stored document to be printed, as well as the number of copies of the document that are to be printed. The control panel can also provide setup and diagnostic features.

Figure 12 is a simplified view of one possible configuration of a printer. Many other configurations are possible. The detailed design of paper transport mechanisms is well known in the industry, and can be accomplished by engineers skilled in the art.

Figure 13 shows a perspective view of the major components for one possible configuration of the commercial printing system. The printer system is approximately 1.8 meters tall. In this example printer configuration, there are six ink reservoirs 578. These are for the colors 213 density cyan, 1/3 density cyan, 2/3 density magenta, 1/3 density magenta, yellow and black that are used in the CC'MM'YK color model. If other color models are used, a different number of ink reservoirs 578 may be required. Each ink reservoir 578 supplies ink to an ink pressure regulator 579. If the ink pressure regulators are positioned an appropriate height above the print heads, then the ink pressure can be regulated with high accuracy and stability using a simple float valve. In this case, the ink pressure is provided by the weight of ink in the column above the heads.

Paper (or some other recording medium) is supplied on a roll 575 in a removable frame 576. When printing, the paper roll 575 rotates, supplying paper to the web 560. The paper web is tensioned by a tensioning system 583. One side of the web is printed by the print head assembly 564. The paper then passes through

the drying section 582, which passes heated forced air over the paper web. The paper preferably makes at least two passes through the drying section 582 before encountering rollers 562 which contact the newly printed side of the paper. The temperature, airflow, and size of the drying section depends upon the characteristics of the ink used, especially the drying characteristics of the ink carrier. After passing through the drying section 582, the other side of the paper web is printed by the print head assembly 563.The paper web then passes through the drying section 582 again. Again, it is preferable that the paper web makes at least two passes through the drying section 582 before encountering rollers 562 which contact the newly printed surface of the web.

Sheets of paper are cut from the paper web by the cutter 569. Each sheet contains four A4 pages. The sheets may be printed in collated order, ready for binding and trimming. The paper sheets are shown forming a stack in a motorized paper output tray 570. Alternatively, the printed paper sheets may be supplied directly to an automated saddle stitching and trimming machine, or other bindery equipment.

An electronics subsystem 561contained the control electronics and electronic collation system, power supplies, power electronics, and a hard disk drive.

Figure 13 is intended to be representative only, and does not show all of the required components of the system. Items not shown include: connections to a computer or power source; electrical wiring between subsystems of the printer; ink transport systems; ink heating systems if hot melt ink is used; paper guides; drive motors gears, belts, or chains for the paper transport mechanisms; covers for the printer, and so forth. These are well known in the art, and depend upon the configuration of the printer.

Figure 14 shows a perspective detail diagram of the region of the print head assemblies 563 and 564. Each head assembly 563 and 564 is made from two monolithic print heads 50, each of which prints half of the web width on one side of the web 560. The four print heads 50 are all at the same height, allowing gravity feed from common ink reservoirs to provide the same ink pressure. Ink is provided from the ink pressure regulators (579 in figure 13) to the heads 50 via ink supply tubing (not shown) and ink channels 75. Power and data are supplied to the heads 50 from the electronics subsystem (561 in figure 13) via electrical wiring (not shown). The platens 67 hold the paper web 560 at the correct distance from the print head 50. The platens 67 preferably extend the full width of the web to prevent buckling of the web in the centre.They are shown extending half the width of the web to show the positions of the print heads, which are on the underside of the web 560, directly below the platens 67. The platens 67 are preferably mounted on a frame which is raised by a few centimeters whenever a new roll of paper is to be threaded through the printing system. When printing, the platens are lowered onto the web. In the case of electrostatic drop separation printing, the platens 67 may form one electrode of the electrode pair generating the electrostatic field, and the head 50 may form the other electrode. In the case of proximity drop separation printing, the gap between the platens 67 and the heads 50 is very small, and must be accurately controlled.When the mechanical frame containing the platens is lowered after threading the web through the printer, it is unlikely to return the platens 67 to a distance from the heads 50 which is sufficiently accurate to ensure good print quality. The platens 67 may be mounted on piezoelectric positioners, which are then mounted on the frame. When the printer is started after threading the web, a calibration sequence may be initiated. This calibration sequence is preferably automated, using sensors which detect the print density (not shown). Alternatively, the calibration sequence may be manual, requiring an operator to adjust the platen position based on print density of sample images. The paper transport rollers 65 position the web to be in slight tension against the platens 67.

Figure 15 shows a roll of input paper in a mobile frame. A single roll of paper 575 with a diameter of 800 mm and a width of 420 mm would contain approximately 100,000 A4 pages, take approximately 11 hours to print at full print speed, and weigh approximately 140 kg. The roll of paper can be mounted in a frame with castors 576, to allow installation and removal without lifting equipment.

Rotation of the roll should be motorized, under control of the computer system. A feedback system which controls roll rotation speed in response to the radius of paper remaining on the roll should be incorporated into the printing system. The high angular inertia of the roll of paper 575 makes fast starting and stopping of roll rotation difficult. A system for maintaining paper tension should be incorporated into the printer system.

The foregoing describes various general and preferred embodiments of the present invention. Modifications, obvious to those skilled in the art, can be made without departing from the scope of the invention.